BIOLOGICAL RESPONSES OF 155mm HOWITZER CREWMEN TO AIRBORNE LEAD

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ABSTRACT

Lead health effects are largely unknown for short-duration, high-concentration exposures resulting from weapon firings. Cumulative air lead exposure proved to have a significant statistical relationship with the change in blood lead over the period of the study.. Small, but statistically significant changes occurred in both hematocrit and Free Erythrocyte Protoporphyrin (FEP). All but four study subject exceeded mean 24-hr exposures for airborne lead (PbA) using the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 16.7 $\mu g/m^3$. Significant PbA exposures were reliably associated with the firing of high-zone M119 and M203 charges but not low-zone charges. Baseline blood lead concentrations (PbB) were quite low for all groups, despite evidence for recent prior exposures Blood lead increases did not exceed the OSHA Action Level of 40 $\mu g/dL$ although twelve individuals had blood lead levels in excess of 30 $\mu g/dL$. Statistically significant correlations could be found between maximum (peak) blood lead levels and mean 8-hr time-weighed airborne average (TWA). Large NCV decreases of 8.0 and 11.6 m/sec were found in the ulnar sensory nerve for two of the M109A3 crewmen. Statistically significant NCV decreases were found for the peroneal motor nerve during the period following exposure.

EXECUTIVE SUMMARY

Lead has been used as a decoppering agent in artillery systems for many years, but health effects are largely unknown for short-duration, high-concentration exposures resulting from weapon firings. Because of increased concern about lead exposure, studies were conducted on the physical/chemical characterization of lead aerosols during firings of the 8-inch howitzer and the M109 155mm howitzer, on biological responses in artillery crewmen during operational tests of the 8-inch howitzer, and during operational tests of the product-improved 155mm howitzer inprovment project (HIP), the M109A3E2.

Cumulative air lead exposure proved to have a significant statistical relationship with the change in blood lead over the period of the study. The slope of a regression line between these two variables immediately after the firing exercise was approximately tenfold less than experimental studies of humans exposed continuously, but was approximately the same when the blood lead concentrations at delayed post exposure were considered. Small, but statistically significant changes occurred in both hematocrit and Free Erythrocyte Protoporphyrin (FEP).

From the airborne lead study, all but four study subject mean 24-hr exposures for airborne lead (PbA) exceeded the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 16.7 $\mu g/m^3$. Eighty-six percent of the subject's highest 8-hr and 100% of the highest concentration-time product exposures exceeded the PEL of 50 $\mu g/m^3$ and 24,000 $\mu g\text{-}min/m^3$. The 24-hr PEL for air lead was exceeded by a six-fold margin 26% of the time during the 3 exercises in the test. Significant PbA exposures were reliably associated with the firing of high-zone M119 and M203 charges. Mean exposures during the firing of low zone charges did not exceed the PEL. Weapons systems differences were apparent with M109A3 crew exposures significantly higher; however, A3 crews had a higher round total in the third exercise. Gun crews had higher exposures for HIPs in the final two exercises and for M109A3s in all three exercises. HIP gunners had lower mean exposures than A3 gunners, suggesting that the cab filter may have been beneficial in protecting the HIP gun crew.

From the blood lead study, statistically significant differences in PbA existed between HIP and A3 sections in two out of the three exercises. The section with the higher round total had the higher exposure. Significant correlations between the mean 8-hr TWA and the mean number of rounds were made during these same periods. Wind-related factors may have been important in the third exercise for HIPs and the first exercise for A3s. This may be especially true when round totals did not support higher concentrations and winds were blowing from one section to another. Exposure from firing as few as 3 to 5 M119 and M203 charges appear to equal or exceed the PEL. Exposure concentrations for periods when large numbers of rounds were fired may have been under-estimated as a result of overloaded sample filters. The overall exposure may have also been less than worst-case due to favorable wind patterns. Baseline blood lead concentrations (PbB) were quite low for all groups, despite evidence for recent prior exposure in the M109A3 population as evidenced by elevated FEP. The mean baseline PbB was below U.S. population mean and a survey of military recruits. Blood lead increases did not exceed the OSHA Action Level of 40 $\mu g/dL$, which requires medical surveillance and employee notification. Twelve individuals had blood lead levels in excess of 30 $\mu g/dL$, a level in which OSHA requires employee counseling if fathering children is being considered. The majority of blood lead increases occurred during the training period for both HIP and A3 crewmen. There were no differences in mean blood lead level between HIPs and A3s at the first measurement point; however, the rate of PbB increase was faster for the M109A3 crewmen. Statistically significant

correlations could be found between maximum (peak) blood lead levels and mean 8-hr time-weighed average (TWA) overall, and for both weapons systems; but when examined by exercise, the correlations existed only for the A3s in the last two exercises. Correlation coefficients indicated that a linear model provided a strong explanation for the relationship between peak blood lead levels and mean 8-hr TWA. Blood lead values peaked for both populations after the second exercise and declined slightly after the third, despite continued high air lead exposures. Blood lead achieved $t_{1/2}$ decreases during the 58 days following exposure for both populations, but the six individuals with the highest PbB lagged behind. Free Erythrocyte Protoporphyrin was elevated for A3 crewmen at baseline, and HIP crewmen had higher PbB and Hematocrit (Hct), but the absolute values for both populations met the clinical definition of normal. More M109A3 crewmen had elevated FEP than HIP crewmen. FEP increases were more consistent for the A3 population and the classical lag in FEP increase was more obvious in this population. FEP increased through all exposure periods and decreased during the period following exposure. Fourteen crewmen exceeded the Centers for Disease Control (CDC) FEP limit of 35 $\mu g/dL$ during at least one exercise. Although the mean Hct of 43.9% is considered clinically insignificant, 29% of the HIP and A3 lead study populations fell below 42% Hct (a benchmark used to show exposure to lead) following exposures. Recovery was evident by the first measurement period. Hemoglobin values also fell below 14 $\mu g/dL$ for 29% of both populations during the same period. High carboxyhemoglobin (COHb) levels may have depressed FEP readings by the analytical laboratory since analytical corrections were not made. Based upon indirect evidence, carbon monoxide levels in the artillery crewmen were quite high (20-30% COHb).

From the nerve conduction velocity (NCV) study, large NCV decreases of 8.0 and 11.6 m/sec were found in the ulnar sensory nerve for two of the M109A3 crewmen. Statistically significant NCV decreases were found for the peroneal motor nerve during the period following exposure. Statistically significant NCV decreases were found for the sural sensory nerve following exposure. Other less reliable decreases were found for the ulnar sensory nerve and the ulnar motor nerves. Statistically significant correlations were found for the relationship between maximum (peak) PbB and the median sensory nerve and rise in PbB from true baseline and the ulnar motor nerve; however, the correlation coefficients were not very strong.

Recommendations include:

Provide information to combat physicians on lead hazards of artillery. Until lead-based ammunition is eliminated, the potential for lead poisoning during extended periods of firing high-zone charges in combat will exist. Blood lead and FEP/ZPP measurements under these circumstances may be warranted.

Restrict soldier exposure during training by requiring the use of respiratory protection and medical monitoring when firing high-zone charges.

Develop an alternate decoppering material as a substitute for lead.

Develop alternate medical monitoring procedures for ZPP to correct for the presence of carboxyhemoglobin.

Examine artillerymen who fought in the DESERT STORM operation for residual lead effects, including PbB, FEP, NCV, and bone lead. In particular, individuals who were part of previous USABRDL studies (8-in Crew Ballistic Shelter, chronic effects and reproductive effects Studies) and this study (HIP IOTE) should be examined since baseline data exists on these individuals.

Initiate a cross-sectional chronic effects study of artillery-based lead.

Collect data from future exposure studies to describe lead elimination. Samples of urine and feces should be taken in order to determine the proportion of inhaled weapons lead that is eliminated by the body. Follow-up on at least a selected number of subjects over an extended period of time (> 1 yr).

Consider conducting neurobehavioral and peripheral nervous system experiments following field exposures to artillerymen.

Conduct future studies during extended artillery firing exercises to establish definitive data on carbon monoxide and the relationship between COHb, FEP, and Hb during these exposures.

Develop improved air lead sampling techniques in order to eliminate air sampler filter clogging problems. Suggested techniques might include more frequent sample filter replacement or size-selective collections.

Incorporate in future studies which measure nerve conduction velocity, measurement of blood copper (CuB), in order to evaluate the potential impact of the antagonistic behavior between PbB and CuB.

NOTICE

Disclaimer

The findings in this report are not to be construed as an offical Department of the Army position unless so designated by other authorized documents.

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Human Subjects

The investigators have adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25.

Disposition

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ABBREVIATIONS/GLOSSARY

ANL	Argonne National Laboratory
BL	Baseline measurements
cm	centimeter
dl	deciliter
DPE	Measurements taken approximately 8 weeks after the end of exposure
FAASV	Field Artillery Ammunition Support Vehicle
FEP	Free Erythrocyte Protoporphyrin
Hb	Hemoglobin
Hct	Hematocrit
HIP	Howitzer Improvement Program
hr	hour
in	inch
IOTE	Initial Operational Test and Evaluation
IPE	Measurements taken after the third exercise and after all firing for the IOTE had ceased
l	liter
lpm	liters per minute
µg	microgram
µm	micrometer
mg	milligram
ml	milliliter
mm	millimeter
m/sec	meters per second
MOPP	Mission Oriented Protective Posture
ms	milliseconds
NCV	Nerve Conduction Velocity
NIOSH	National Institute for Occupational Safety and Health
nm	nanometer
OSHA	Occupational Safety and Health Act
OTEA	Operational Test and Evaluation Agency
PbA	Airborne lead
PbB	Blood lead
ΔPbB	Change in blood lead
PEL	Permissible Exposure Limit
POST1	Measurements taken after the first exercise
POST2	Measurements taken after the second exercise
PRE1	Measurements taken prior to the first exercise
TWA	Time Weighted Average
USABRDL	U.S. Army Biomedical Research and Development Laboratory
USAMRD	U.S. Army Medical Research Detachment
WRAIR	Walter Reed Army Institute of Research
ZPP	Zinc Protoporphyrin

INTRODUCTION

Artillery weapons systems have used lead as a decoppering agent for many years without concern being expressed for health effects. The potential for increased use of lead in higher zone charges (the zone size reflects the amount of propellant used; with higher zone charges providing greater range), the review of health hazard issues in developmental weapons systems and reports of high air lead levels during engineering development tests have prompted an increased awareness of the need to further explore weapons lead-related health issues. The Office of the U.S. Army Surgeon General and the U.S. Army Medical Research and Development Command established a priority for investigating the health effects of lead aerosol from artillery systems and assigned the responsibility to the former U.S. Army Biomedical Research and Development Laboratory (Reference 1), now the U.S. Army Medical Research Detachment of Walter Reed Army Institute of Research, located at Wright-Patterson Air Force Base, Ohio. As a result of this initiative, studies were conducted on the physical/chemical characterization of lead aerosols during firings of the 8-inch howitzer and the 155mm howitzer and on biological responses in artillery crewmen during operational tests of the 8-inch howitzer. In the spring of 1988, USABRDL was also provided an opportunity to participate in operational tests of the product-improved 155mm howitzer, also known as the M109A3E2(HIP). This report describes a study during these operational tests on the results from air lead sampling and biological monitoring. Other studies have subsequently been conducted on the chronic health risks (nerve conduction velocity (NCV) changes and bone lead deposition) in different age groups of artillerymen and potential reproductive hazards.

The aerosols are generated as a result of dissemination of elemental lead (Ref 2) following combustion of the gun propellant which contains, in low zone charges small amounts of the lead as lead carbonate in the primer plus, in the high zone charges, lead foil. This mode of lead aerosol generation differs from that obtained using small caliber weapons in indoor firing ranges. A small caliber weapon generates minor amounts of lead aerosol from lead compounds in the propellant, but generates most of the lead aerosol by mismatches between the revolver and barrel in handguns or in barrel erosion of the slug, which results in particulate aerosols, probably larger in Mass Median Diameter (MMD) than the aerosol generated by recondensation of lead vapor (Ref 3, 4).

PREVIOUS STUDIES OF EXPOSURE TO LEAD IN ARTILLERY EMISSIONS

Epidemiological studies of exposure to artillery-generated lead aerosol are limited. A study of British 105mm gunners was conducted in 1983 (Ref 5). Thirty-five soldiers with duties as a practice and demonstration unit for the Royal School of Artillery were selected as the study subjects, with 295 recruits as a control population. Tests were conducted on a towed 105mm howitzer (no cab), with measurements made for air lead, blood lead and urinary aminolevulinic acid. Eight air lead samples were collected over a 4-hr and 45-min sampling period when low zone rounds were fired; and 10 samples were collected for high zone charges. Calculated 8-hr time-weighted averages for the low zone charges were considered insignificant, but the time-weighted average (TWA) for one day of high zone firings resulted in a value of 0.19 mg/m^3, which proved to be in excess of the British occupational health standard of 0.15 mg/m^3. Blood lead values ranged from 9.6 µg/dl to 30.1 µg/dl, with a mean of 19.25 (SD 4.9), which proved to be significantly different than the recruit population mean of 14.5 µg/dl. Values for urinary aminolevulinic acid were within normally expected ranges. Because high zone charges are fired no more than 3 days per month, the authors calculated exposures due to a mix of high zone and low zone charges for a 40-hr week which resulted in a TWA of 0.03 mg/m^3. They concluded that special monitoring or corrective measures were not required by British Law. The study period included air sampling and exposure over a period of severe weather including wind and snow. Additionally the study population was quite small. As noted in the report, exposure is expected to be higher in weapons which include an enclosed cab and for the 155mm self-propelled howitzer, the high zone charges contained significantly more lead. For these reasons, exposure to lead emissions from the 105mm howitzer in general, and for the study conditions cited, were probably minimal.

The U.S. Army Medical Department Activity (MEDDAC) at Ft. Sill, OK evaluated lead and carbon monoxide exposures which occured during operational tests of the M109 Howitzer Extended Life Program (HELP), June-July 1985 (Ref 6). Air lead measurements were taken at two fixed positions within the cab of the howitzer. Twenty sample collections were made in two different howitzers, with two of the samples being in

excess of the Occupational Safety and Health Act - Permissible Exposure Limit (OSHA PEL) of 0.05 mg/m^3, and three others were above the OSHA action level of 0.03 mg/m^3. Blood samples were taken from twenty crew members at baseline, after the last firing scenario (+ 6 weeks) and 120 days after baseline. Blood samples were analyzed for blood lead (PbB) and Zinc Protoporphyrin (ZPP). Each crew member had a brief physical exam before the exercise started, as well as completing a clinical and workhabits questionnare. At six weeks the highest PbB value was 33 μg/dl; by 17 weeks the value of the highest blood lead had declined to 17 μg/dl. Mean PbB at six weeks was 16.19$\pm$6.23 μg/dl. None of the ZPP values were in excess of 55 μg/dl as compared to the OSHA limit of 70 μg/dl.

The Ft. Sill MEDDAC results were examined in detail by Argonne National Laboratory (ANL) (Ref 7). By combining the data for both the 15-min and 12-hr collections, 12-hr TWA concentrations were estimated to be at or slightly above the OSHA action level (0.03 mg/m^3), although many of the sample collections were plagued by overloaded and clogged filters and may have underestimated actual air lead levels. Data from the 15-min collections suggest that transient levels may have been as high as 1 mg/m^3. Inspection of PbB values lead ANL to believe that increases at 6 weeks may have been as a result of gradual increases over the six week period plus a component resulting from exposure during the last day of firing. ANL was unable to obtain a meaningful correlation from the MEDDAC data between PbB and ZPP. The blood data also seemed to be somewhat affected by varying times of blood sample collection after the last firing period. Those individuals sampled immediately after the last firing period had the highest PbB values.

Bhattacharyya et al (Ref 2) conducted studies on the relationship between air lead, blood lead, blood hematocrit, blood free erythrocyte protoporphyrin (FEP) and peripheral nervous system response during an operational test of the 8-in Howitzer. Firing of high zone charges resulted in 24-hr mean TWA's in the highest exposed group of 11 μg/m^3. Maximum air lead concentrations occurred when 1 - 5 knot head winds were recorded, resulting in 60 μg/m^3 over the period of active firing (20 high zone charges in 12 hrs). Mean blood lead increased from 5 - 6 μg/dl at baseline to 8 - 11 μg/dl immediately after the end of firing exercises. The maximum blood lead for any individual was 17 μg/dl. Maximum blood lead rise occurred in the first 12 days and leveled off thereafter despite continued exposure to high air lead concentrations. Individuals from the unit with the highest exposure were still at a mean 5.4 μg/dl at 6 weeks delayed post-exposure as compared with baseline.

Cumulative air lead exposure proved to have a significant statistical relationship with the change in blood lead over the period of the study. The slope of a regression line between these two variables immediately after the firing exercise was approximately tenfold less than experimental studies of humans exposed continuously, but was approximately the same when the blood lead concentrations at delayed post exposure were considered. Small, but statistically significant changes occurred in both hematocrit and FEP. Similar small changes occurred in conduction velocities of motor and sensory nerves, but interpretation of these changes were confounded by problems with adjustment for skin temperature.

PREVIOUS AIR LEAD MEASUREMENTS ON HIP

The Howitzer Improvement Program (HIP) is an extensive product improvement effort designed to meet deficiencies in the current M109A2/A3 self-propelled howitzer. The HIP vehicle, designated M109A3E2, is an armored, fully tracked howitzer carrying a minimum of 34 conventional rounds and 2 oversized projectiles. The weapon has a crew of 4, including the driver, and is part of a gun section which includes the Field Artillery Ammunition Supply Vehicle (FAASV), designated M992. The FAASV has a crew of 3 and normally operates in close proximity to the howitzer during firing missions (Figure 1).

The HIP product improvements were designed to improve the survivability, reliability, maintainability, and availabilty of the new system as compared to the current system. There are several features of howitzers in general, improvements to the HIP, and uncontrolled variables, such as wind speed and direction which influence the potential exposure of crew members (Ref 8). Howitzers typically have cab ventilators which may be operated in either an exhaust or intake mode. The gun barrel also contains a pressure-actuated chamber (bore evacuator) which removes exhaust products. At times, apparently influenced by wind speed and direction, the cab ventilator in exhaust mode has been shown to overcome the effects of the bore evacuator, and draw weapons exhaust into the cab (Ref 9). A modified muzzle brake also directs propellant exhaust back towards the cab rather than

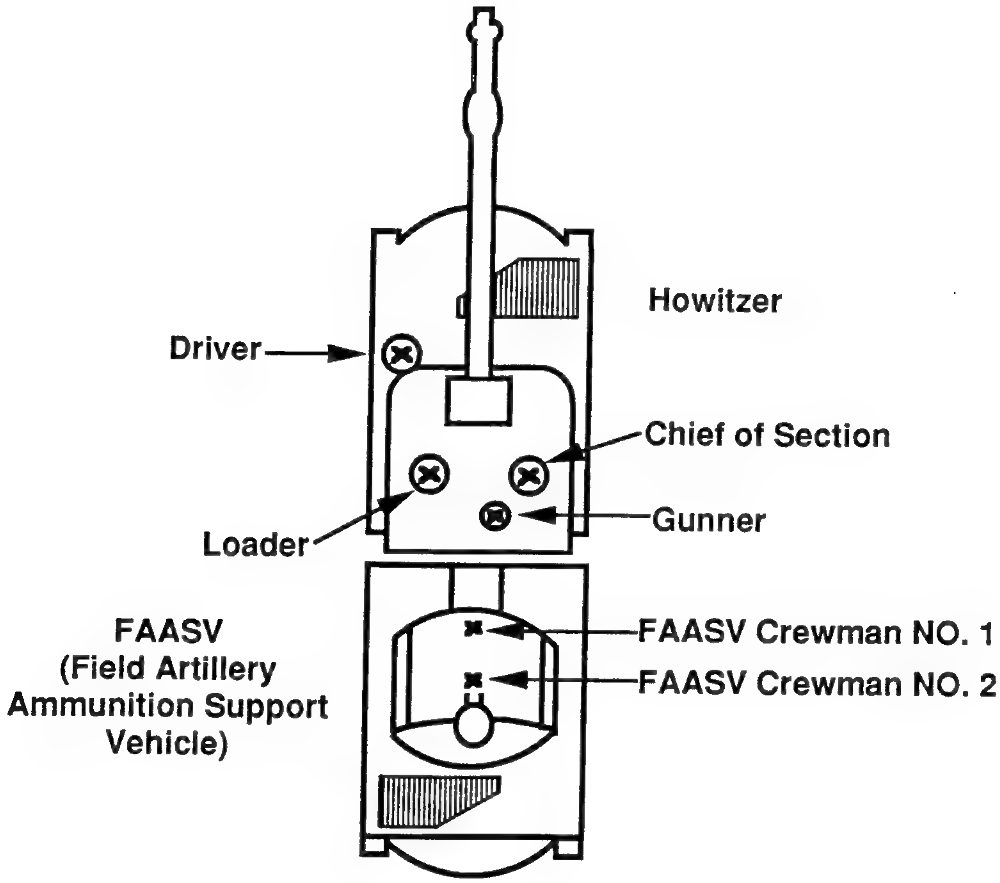

Figure 1. Vehicle Orientation During Firing Phase

perpendicular to the gun tube, as in the current howitzer. When firing the M203 charge, the hatches are required to be closed in the HIP and the FAASV to protect the crew against blast overpressure. Since the M203 charge has the highest lead content of the rounds currently in use, closing of hatches can be expected to decrease the ventilation and subsequent dilution of the exhaust exposure which is produced by the breech.

Engineering tests of the HIP prototype included sampling to determine the influence of windspeed and direction, hatch configuration, muzzle brake configuration, and insertion of a particulate filter in the ventilator during intake mode, on lead concentration. Based upon this data, the U.S. Army Environmental Hygiene Agency prepared a health hazard assessment report (Ref 9) which identified numerous variables affecting combustion product concentrations, including: firing elevation, wind direction/speed, hatch configuration, ventilator mode, propellant, HIP component failure (e.g. damaged bore evacuator), sample volume and rate-of-fire. Based upon an analysis of lead sampling data collected by the U.S. Army Combat Systems Test Activity (CSTA), Aberdeen Proving Ground, the influence of these variables on air concentrations could be demonstrated, as illustrated in a table from the report (Table 1). Lead levels for identical firing scenarios were often dissimilar and high air lead concentrations during the firing of low lead rounds often led to questions as to the reliablity of the observed data.

TABLE 1

Comparison of HIP Lead Test Data under Similar Configurations

Charge	Pb ($\mu g/m^3$)				Vent Mode	QE* (Mils)	Hatches	
	Driver	Gunner	Loader	Chief of Section			Side	Rear
M203	440	470	1040		Exhaust	90	Closed	Open
M203A1	6		107	75	Exhaust	750	Closed	Open

*QE - Elevation of gun barrel

General conclusions as to the reasons for the observed variablility were cited:

a. The highest levels of exposure occurred when all hatches were closed and the ventilator was in the exhaust mode. This condition evidently creates a negative pressure in the crew compartment and draws combustion products from the gun tube when the breech is opened.

b. Combustion product levels appear to be higher when headwinds are present.

c. A muzzle brake which is at 45° to the gun tube will blow combustion products back towards the crew compartment as contrasted with the muzzle brake on the M109A3 which is at a 90° angle to the gun tube, and will blow the emissions perpendicular to the gun tube.

Lead levels projected for the Initial Operational Test and Evaluation (IOTE) were estimated based upon the Operational Mode Summary/Mission Profile and from averages computed by CSTA during previous developmental testing. In one test, the average lead concentration per round for the M119 charge was 109 $\mu g/m^3$ and for the M203 charge was 159 $\mu g/m^3$. For the second test, 1880 $\mu g/m^3$ was the average reported for the M119 charge and 1128 $\mu g/m^3$ for the M203 charge. Based upon an estimate for firing of 81 M119 charges and 20 M203 charges, one set of test data predicted that daily exposures would exceed the OSHA TWA-PEL (Ref 11) by a slight margin (24,018 $\mu g\text{-}min/m^3$); the second set of data predicted that the PEL would be exceeded by a considerable margin (45,120 $\mu g\text{-}min/m^3$). With these projections, the HHA recommended that respiratory protection and medical monitoring be required during the IOTE.

The HHA was updated in March 1989 (Ref 10) to incorporate data from firings at Yuma Proving Ground (YPG) (Ref 12) during the period 19 - 29 January 1989 and to reassess data evaluated earlier. Firing took place during "move and shoot" operations, as contrasted with data collected during static firings at APG. The YPG tests also included evaluation of the effectiveness of a filter added to the existing ventilator.

Air sampling data from the evaluation are included in Table 2. Air lead concentrations at the gunner's position proved to be consistently higher than at other positions monitored. As a result, all projections of estimated dose for the upcoming IOTE were based upon values observed for the gunner's position. Table 3 is a summary of these estimates.

For firings of the howitzer without a filter in place, average values fell between the two OT projections previously reported (Ref 9). The estimated dose of 145,012 $\mu g\text{-}min/m^3$ was 6 times greater than the PEL. With the filter in place, the estimated lead dose at the gunner's position was 14,400 $\mu g\text{-}min/m^3$, which was below the PEL, but above the action level cited in Federal Regulations (Ref 11).

Variability due to wind speed and direction was also quite apparent in the YPG data. Observed values for gunner's lead dose on two different days were reported to be 3115 and 14,030 $\mu g\text{-}min/m^3$, with the higher value occuring when the wind blew muzzle combustion products back towards the howitzer. High lead values were observed to occur even for the low lead M3/M4 charges when wind direction allowed maximum exposure for the crew. The report recommended development of a new decoppering material as a replacement for lead, medical monitoring and hazard training. In the event the filtration system was not used, respiratory protection was required to meet Federal Regulations.

Bhattacharyya et al (Ref 2) conducted chemical and physical characterization of both the M109A3E1 and the HIP. Particle concentrations were elevated in these howitzers for periods of 3 - 6 min when measured at the breech by optical particle counters. Eighty to eighty-five percent of the lead in the aerosol was associated with particles less than 0.3 μm aerodynamic diameter. Breech aerosols contained roughly spherical particles 0.5 - 5 μm diameter and 3 - 6% lead by weight. The muzzle aerosol was predominantly lead rich spheres of the same size that were 20 - 25% lead by weight. Air lead concentrations at crew positions were in the range of 100 - 200 $\mu g/m^3$, regardless of meteorological conditions. Muzzle blast aerosol concentrations ranged from 150 - 600 $\mu g/m^3$ and were much more dependent on meteorological conditions. Minor differences were found between exposure characteristics in the M109A3 and the HIP weapons. These included a slightly lower lead content in the muzzle blast aerosol for the HIP than for the M109A3 (17.5 $\pm$2.6% versus 18.5 $\pm$1.6% by weight, respectively) and a higher concentration for the muzzle blast aerosol in the HIP (427 - 627 $\mu g/m^3$) than in the M109A3E1 (109 - 496 $\mu g/m^3$).

TABLE 2

Howitzer Improvement Program
Yuma Proving Ground
Lead Particulate Data[1]

Sample Location	Prop. Charge[2] M3	M4	M203	MII9	Date (Jan 89)	Time (min)	Sampling Conc. µg/m³	Pb Dose µg-min/m³	Pb[3] Filter[4] Status
Commander	16	15			19	90	3	270	On
			8		19	86	6	510	On
				8	19	80	3	240	On
	15	15	8	32	19	385	3	1156	On
	30	30	8	32	19	445	4	1780	On
Gunner	15	15			19	90	6	540	On
			8		19	85	13	1105	On
				8	19	80	10	800	On
	15	15	8	32	19	385	6	2310	On
	30	30	8	32	19	445	7	3115	On
Commander		30			20	65	3	196	On
			8		20	50	39	1950	On
				8	20	40	73	2929	On
		30	8	32	20	245	55	13475	On
	30	30	8	32	20	305	44	13420	On
Gunner		30			20	65	9	585	On
			8		20	50	36	1800	On
				8	20	40	59	2360	On
		30	8	32	20	245	51	12495	On
	30	30	8	32	20	305	46	14030	On
Commander	15	15			24	82	15	1230	Off
			8		24	45	417	18765	Off
				8	24	25	377	9425	Off
	15	15	8	32	24	270	113	30510	Off
	30	30	8	32	24	330	101	33330	Off
Gunner	15	15			24	82	14	1148	Off
			8		24	45	495	22275	Off
			8		24	25	330	8250	Off
	15	15	8	32	24	270	120	32400	Off
	30	30	8	32	24	330	108	35640	Off
Commander	15	15			24	80	134	10720	Off
			8		25	40	752	30080	Off
				8	25	35	265	9275	Off
	15	15	8	32	24/25	220	279	61380	Off
	15	45	8	32	24/25	285	219	62415	Off
Gunner	15	15			24	80	182	14560	Off
			8		25	40	826	33040	Off
				8	25	35	Sample Failure		
	15	15	8	32	24/25	220	314	69080	Off
	15	45	8	32	24/25	285	282	80370	Off

Table 2 (Cont.)

[1] Data extracted from Yuma Proving Ground Laboratory Services Branch Test Report, 1 February 1989 (Ref 12)

[2] Propellant charge types were M3AI, M4A2, M203A1 and M119A2. The number of propellant charges listed are cumulative for each location on a given day.

[3] Lead dose in μg-min/m³ is the product of sampling time and lead conc.

[4] Filter status "on" refers to the filtration system being installed and operational. Filter status "off" refers to the filtration system not being installed.

TABLE 3

Howitzer Improvement Program
Operational Test
Lead Dose Estimates

Filtered (19/20 January 1989):

$$\text{Dose}^{1} = \frac{3115\ \mu\text{g-min/m}^3 + 14{,}030\ \mu\text{g-min/m}^3}{2} \times 2.5$$

$$= 8572.5\ \mu\text{g-min/m}^3 \times 2.5$$

$$= 21{,}431\ \mu\text{g-min/m}^3$$

Unfiltered (24/25 January 1989):

$$\text{Dose} = \frac{35{,}640\ \mu\text{g-min/m}^3 + 80{,}370\ \mu\text{g-min/m}^3}{2} \times 2.5$$

$$= 89{,}005 \times 2.5$$

$$= 145{,}012\ \mu\text{g-min/m}^3$$

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[1] Dose from Table 2 = average of 2 gunner samples with all rounds fired x 2.5 to equal number of rounds expected to be fired for the IOTE

STUDY OBJECTIVES

1. To collect data for evaluating the hypothesis that short-term, high concentration exposures to weapons aerosol lead did not result in greater hazards than individuals chronically exposed to equivalent air lead exposures.
2. To characterize changes in blood lead, FEP, Hct, Hb and nerve conduction velocity that resulted from exposures during the HIP IOTE.
3. To characterize differences in exposure between the existing type-classified M109A3 howitzer and the developmental prototype HIP howitzer, particularly with respect to the effectiveness of the ventilation system filter installed in the HIP howitzer.

MATERIALS AND METHODS

STUDY POPULATION

Medical Surveillance Subjects

Because the Office of the Surgeon General had recommended that all artillerymen exposed to weapons aerosol during the IOTE (Ref 10) be in a medical monitoring program in order to comply with OSHA regulations, blood samples were collected from all gun crews at pre-exposure (Baseline-BL), immediately after the end of IOTE (Immediate Post-exposure - IPE) and approximately eight weeks after exposure (Delayed Post-exposure - DPE). Additional crewmen who joined the test units after March had a baseline measurement on 8 June. One hundred and eight individuals had at least one blood sample taken - 48 HIP crewmen and 60 M109A3 crewmen. The blood collection and sample analysis were the responsibility of the Ft. Sill MEDDAC. Because samples were taken for medical monitoring purposes, these subjects were not volunteers. Data on blood parameters was provided to USABRDL for analysis. Subjects with only BL, IPE, and DPE samples are referred to in the narrative as "medical surveillance subjects", or marked in the report as numbers higher than 31, with a B suffix (e.g. 32B).

Lead Exposure Study Subjects

USABRDL estimated that available research team members, sample pumps and other logistical constraints would limit air sampling to crewmen of two HIP guns (out of four available) and two M109A3 guns (out of four available). All gun crew members were solicited as volunteer subjects. Fourteen HIP crewmen and 17 M109A3 crewmen volunteered as study subjects. Study subjects had to wear air sampling pumps and filter cassettes during each of the three exercises. Study subjects had three more blood samples taken than the three taken for medical surveillance subjects. These additional three included one before IOTE firing exercises were initiated but after pilot and training firing exercises (PRE1), after the end of the first exercise (POST1), and after the second exercise (POST2). In addition, study subjects received measurements for nerve conduction velocity at PRE1, IPE, and DPE. Study subjects completed a detailed questionnaire related to personal habits, occupational history and other factors which may have had a bearing on prior lead exposure history (Appendix A). The questionnaire was the same as used in the 8-in study (Ref 2). These subjects are referred to in the narrative as "lead exposure study subjects" and marked in the report as numbers 1 - 31 with a suffix of AB (e.g. 18AB).

MEASUREMENT OF AIR LEAD CONCENTRATIONS

Air Sampling

The sampling procedures as well as the analytical procedures described in subsequent paragraphs followed NIOSH Method 7082 (Ref 13). Specifically, a high-flow air sampling pump (Gillian DHFS-113 dual high-flow air sampler, SKC universal constant-flow air sampler, or the Dupont P4000 pump) was calibrated to draw air at 2 $\pm$ 0.2 lpm before each nominal 8-hr sampling period using a Gilibrator^{R} automated primary standard. After the sampling pumps were calibrated, a clear plastic filter cassette with an 0.8 µm mixed cellulose ester filter was connected to the air inlet on the pump with Tygon^{R} tubing. Pertinent information about the pumps and the sample numbers were recorded in a laboratory notebook along with pump calibration data. Due to the widely separated sampling locations and concurrent exchange of pumps, it was necessary to record some information (pump on and off times, unusual observations) on field data forms (Appendix B) for later transfer to the lab notebook. Column headings on the field data forms were organized in the same order as in the lab notebook to minimize transposition errors during transfer of data. Data were entered by one sampling team member and checked by another. Sampling assemblies and the field data forms for each gun selection were loaded into separate footlockers and transported to the appropriate location. Use of separate footlockers facilitated exchange of pumps under tactical conditions (no white lights allowed) during hours of darkness. The sampling equipment was individually

distributed to the test subjects and previously distributed equipment was retrieved. Sampled subjects were instructed to attach the sampling filter cassette to their outer garment (close to the breathing zone of each person being sampled), in most cases, the undershirt (due to hot weather), and suspended the pump from their belts.

With crew members of both gun systems wearing air sampling pumps continuously for up to 96 hrs, careful prior planning was necessary to meet sampling equipment requirements. The sampling pumps used are rated to operate for 8 hrs before requiring battery recharging. At the end of the 8 hrs of sampling operation, at least 16 hrs are required to completely recharge the batteries. Batteries were color coded in batches for easy identification to preclude re-use before a 16-hr full recharging. During the second and third field exercises, 22 SKC pumps equipped with electronic timers were programmed to run 1 minute on and off alternately to extend the elapsed time from 8 hrs to 16 hrs.

During the distribution of the sampling equipment, the sample number was verified against the person's social security number, the number written on the filter cassette with a permanent felt marker, and recorded on the field data sheet. Filter cassettes remained sealed with manufacturer's plugs in place until the sampling pump was activated. Cassettes were resealed with the plugs at the time of sample retrieval. Any irregularities (such as pump stoppage, broken pump, broken filter cassette, loss of samples, crimped Tygon^{R} tubing) found at the time of sample retrieval were noted. Upon return to the lab trailer, cassette samples were detached from the tubing and placed in a shipping container. The sampling pump was immediately checked for calibration by verifying the flow rates. The collected samples were tallied and checked once more before submitting to the laboratory for analysis. The retrieved pump batteries were then recharged for later sampling. Charged batteries were attached to the pumps, filter cassettes and tubing assembled, pump flow rates calibrated, and pertinent information recorded prior to the next exchange of sampling equipment at the firing points.

Laboratory Analysis

As the collected air samples were received in the Occupational Health Chemistry Laboratory at USABRDL, the laboratory technicians examined the cellulose ester sample filters, and noted any unusual observations that they may have discovered. Each cellulose ester filter was carefully taken out of the cassette and placed in a 100-ml beaker. Three ml of reagent grade concentrated nitric acid was added to the beaker to digest the sample, and the beaker was then covered with a watch glass. A series of 16 beakers was prepared each time, consisting of 12 sample filters; one reagent blank to check spectrophotometric quality, one filter blank for background lead level, one control sample with a known concentration of lead at 1 mg/l, and one spike sample with a known concentration of lead of 1 mg/l on a cellulose filter. Each beaker was heated to and maintained at $140^{o}C$ to allow complete evaporation of the acid. Twice, 2 ml of nitric acid would then be added into the beaker, and the heat was again applied until the nitric acid was completely evaporated. A white ash residue was finally left in the beaker. Three to five ml of 10 percent nitric acid was then used to rinse the watch glass and the wall of the beaker to flush all residue to the bottom of the beaker. The beaker with the sample was then allowed to stand at $140^{o}C$ until the nitric acid solution was completely evaporated. One ml of concentrated nitric acid was added to the residue in the beaker. The residue in the 1 ml solute was quantitatively transferred to a 50 ml volumetric flask and diluted to volume with 1% nitric acid. The resultant concentration in the flask would be the volume of the sample in 50 ml of 3 percent nitric acid.

Analytical Instrument Conditions

Solutions were analyzed for lead on a Perkin-Elmer model 3030 atomic absorption spectrophotometer (AAS) with a hollow cathode lamp. The spectrophotometer wavelength was set at 283.3 nanometers (nm) with a slit width of 0.7 nm. A lean blue, air/acetylene flame was used to atomize the sample solutions. The detection limit for lead using this method was 0.01 mg lead/filter.

Calculations

Peak areas for working standards were plotted against their concentrations, based on absorbance, to obtain a standard curve. The peak areas for each unknown sample and blank sample were compared to the standard curve to obtain concentration in mg/l. The following equation was used to derive the actual concentration of lead on each sample filter:

$$\text{mg Pb/filter} = (C_s - C_b) \text{ X } 50 \text{ ml/filter X } 1 \text{ l/1000 ml}$$

where C_s is the lead concentration of unknown sample, based on absorbance, in mg per liter; and C_b is the lead concentration of the blank in mg per liter.

Quality control

Quality control analysis was performed throughout the period during which the 1,168 air samples were processed to evaluate the instrument variations that may occur from batch to batch, and from day to day. A sample containing 1.0 ppm Pb was analyzed every day that sample analysis was conducted. Precision of these samples, obtained in 10 different runs is listed in Appendix C. Field blanks were all < 0.01 mg Pb/filter, except for one filter which was 0.16 mg Pb/filter. Spike samples were processed to check for analytical recovery efficiency, expressed in percentages. The efficiencies, using spikes that contained 1 - 2 ppm of Pb per liter, varied between 97 and 103 percent throughout (Appendix C). Two hundred and forty-three of the air samples were cut in half in order to save material for further chemical analysis. Five of these had both sample halves analyzed and compared. This data is also in the Appendix C.

MEASUREMENT OF BLOOD PARAMETERS

Blood Sampling

Samples at baseline, PRE1, and DPE were taken in a clean clinic setting. Immediately after the conclusion of firing in each exercise, soldiers were transported to a partially enclosed classroom building on the range. Due to concerns about contaminating blood with environmental lead, trained phlebotomists thoroughly washed each subjects' arms and provided each man with a disposable surgical cap and a surgical gown prior to his entry into the classroom area.

Blood samples were packed in ice and transported to the hospital clinical laboratory where identification labels and lab slips were checked. Samples were shipped by the most expeditious means to a contract laboratory for analysis.

Laboratory analyses

Blood lead, hematocrit, and free erythrocyte protoporphyrin were determined by National Health Laboratories, Dallas, TX. The laboratory was certified by NIOSH for performance of these analytical procedures. Blood lead was determined using a Perkin-Elmer atomic absorption spectrophotometer Model 460 with a Model HGA-2200 graphite furnace. Micro-scale determination of the lead concentration in the whole blood sample was accomplished by comparing peak absorbances for diluted blood to the peaks for lead standards. The zero reading was checked every three specimens and low and medium blood controls were tested every ten specimens with each run. Concentration readings were recorded directly from the instrument (Ref 14).

Free erythrocyte protoporphyrin (FEP) was determined by use of an LS-5 fluorescence spectrophotometer. The FEP's were extracted from whole blood with ethyl acetate:acetic acid (4:1) and then back extracted into 1.5 N HCl. The measurements was made at an excitation of 407 nm and fluorescence emission of 605 nm. The fluorescent intensity was compared to that of a protoporphyrin IX stock standard. A low and high control were run with each extraction (Ref 14).

A Technicon H-6000 automated apparatus was used to obtain the hematocrit values (Ref 14).

Carboxyhemoglobin analysis was also performed by National Health Laboratories. Whole blood was diluted in 0.1N ammonia. Red blood cells were lysed and hemoglobin released is converted to oxyhemoglobin, while carboxyhemoglobin is not converted. The difference between the absorption spectra of these two compounds enables the carboxyhemoglobin to be determined spectrophotometrically. A Hitachi double beam spectrophotometer was used for these analyses (Ref 14).

MEASUREMENT OF NERVE CONDUCTION VELOCITY

Nerve conduction velocity measurements for three motor and three sensory nerves were obtained using a TECA Model TD10MK1 EMG/EP system (TECA Corp., Pleasantville, NY). The motor nerves included the median (MM), ulnar (UM), and peroneal motor (PM) nerves. The sensory nerves measured using antidromic stimulation, were the median (MS), ulnar (US) and sural (SS). Measurement of MM, UM, MS, and US conduction velocities were obtained on the subject's dominant arm from elbow to wrist. Conduction velocities for the PM and SS nerves were measured on the contralateral leg. Skin temperature was monitored on the plantar surface of the hand over the first dorsal interossei muscle for the MM, UM, MS, and US conduction velocity measurements using a skin thermistor connected to a Model 5800 electric thermometer (OMEGA Engineering, Inc., Stamford, CT). Skin temperature for the PM and SS nerves was similarly monitored from the medial surface of the foot, approximately 3 cm distal to the medial maleolus.

The motor nerves that were surveyed were mixed fast and slow fibers. The conduction velocity of the fast fibers was measured by using supramaximal stimulation, with a stimulus duration between 0.05 and 0.5 milliseconds.

Adjustments to nerve conduction velocities related to skin temperature add a degree of uncertainty when skin temperature is below 30°C (Ref 15). In this study, baseline tests included recording of skin temperature. Immediate post-exposure and delayed post-exposure NCV measurements were made with limb temperatures brought within 1°C of baseline temperatures. This was accomplished by using a heated water bath and/or a fan to warm or cool the limb.

Adjustments to the NCV values for temperatures were accomplished using the method of de Jesus (Ref 16). The relationship between skin temperature and velocity as empirically determined by de Jesus is $V_2 = V_1 e^{(M_2 4T)}$ where V_1 = velocity at temperature t_1, V_2 = velocity at temperature t_2, $M_2 = 0.0419$, $4T = t_2 - t_1$, and e = base of natural log.

MEASUREMENT OF METEOROLOGICAL DATA

Meteorological data were collected by Ft. Sill for the purpose of assisting gun crews in computing gun to target calculations. Data collected included date/time and wind direction/speed. Wind direction and speed were reported as an average of measurements from 4 heights (ground level; 1,000, 3000, and 10,000 meters). A single data collection site served the exercise area, and as such may have been quite some distance from individual weapons. Meteorological data were compared with information provided by the Field Artillery Board on gun location, date/time and pointing azimuth, reported separately for HIP and M109A3 weapons. These comparisons allowed for qualitative statements as to whether the exhaust emissions from firing were being blown away from or towards the gun crews.

WEAPONS AND FIRING DATA

Rounds Fired

One data base was prepared by the Field Artillery Board. The data base was prepared by Board observers evaluating each weapon system. Each fire mission was recorded. One file included time, target, firing battery, total rounds and charge type (M119, M203 and low zone charges). A second file included detailed comments on why various guns were unable to complete firing missions. Typically these included maintenance, sleep cycle, pit stop, and out-of-ammo. By comparison of these two files, detailed information on the number of rounds fired in each time period could be computed. For the number of rounds fired during the pilot and training test periods, round firing data were extracted from DA Form 2408-4 (Weapons Record Data).

A second data base was prepared by the Artillery Batteries. Data was entered on DA Form 2408-4. Data entered included date, firing battery, total rounds and charge type.

MOPP and Hatch Status

A small part of the IOTE included a requirement for crewmen to wear respiratory protection as a part of Mission Oriented Protective Posture (MOPP), i.e. protection against nuclear, chemical and biological warfare attack. Field notes of Board evaluators and videotapes were reviewed to determine the time period crewmen wore respiratory protection. This information was used to compensate for air exposure estimates when sampling pumps were operating. Field notes and videotapes were also reviewed to determine if hatches were open or closed.

STATISTICAL ANALYSIS

Data for crewman 8-hr lead exposures were analysed using analysis of variance and presented as means with their standard errors.

Blood lead, free erythrocyte protoporphyrin and hematocrit data for the medical surveillance population (3 time points) were analysed using analysis of variance, with a square root transformation applied to the response variable. Scheffe's multiple comparison procedure was used to compare means. Heterogeneity of slopes was determined using an analysis of covariance procedure. The data are presented as backtransformed means with their associated 95% asymmetrical confidence limits.

Blood lead data for the lead study population (6 time points) were analysed with a square root transformation applied to the response variable followed by regression analysis for point estimation and their associated 95% asymmetrical confidence limits. Heterogeneity of slopes was determined using an analysis of covariance procedure. The data are presented as backtransformed means with their associated 95% confidence limits.

Changes in nerve conduction velocity for each of the six nerves measured were computed by taking the mean NCV from BL to IPE, BL to DPE, and from IPE to DPE and evaluated by a paired t-test to determine if the mean differences were significantly different from zero. Both raw data and temperature adjusted data were evaluated, except for IPE to DPE, which was not temperature corrected.

Correlation between air lead and number of rounds fired were analysed using analysis of variance followed by regression analysis for point estimation and presented as means with their associated 95% confidence limits.

The relationship between air lead and several variants of blood lead (4PbB, Maximum PbB, and rise in PbB from true baseline) were analysed using analysis of covariance followed by regression analysis for point estimation and presented as means with their associated confidence limits.

The relationship between PbB and free erythrocyte protoporphyrin was analysed using analysis of covariance with the blood lead parameter as the covariate. FEP was transformed to log 10 for analysis and means reported as geometric means with their associated 95% asymmetrical confidence limits. Regression analysis was applied for point estimation. The data were analysed for all time points and with day 181 (DPE) eliminated; and for the two subpopulations (medical surveillance and lead study population).

Data for the relationship between PbB and hematocrit; and between PbB and Hb were also analysed with the blood lead parameter as the covariate using analysis of covariance. Regression analysis was applied for point estimation. Heterogeneity of slopes was used to test for interaction. The data were analysed for all time points and with day 181 removed; and for the two subpopulations.

Data for the relationship between COHb and $\log_{10}$ FEP; COHb, and Hb was analyzed on the arithmetic scale. Heterogeneity of slopes was used to test for interaction. Regression analysis was applied for point estimation. The data were analysed for all time points and with day 181 removed; as well as for the two subpopulations.

SAS PROC GLM was used for these analyses (Ref 17).

RESULTS

STUDY SUBJECT POPULATION

General

The schedule for the test events and the samples taken for air, blood and nerve conduction velocity are outlined in Table 4.

TABLE 4

Firing Exercise And Sampling Scenario

Time	Exercise Event	Study Event	Cumulative Days
20-23 March		Baseline blood sample	
14 April	Initiate Pilot test 1		
22 May	Complete Pilot test 1		
17 June	Initiate Pilot test 2		
18 June	Complete Pilot test 2		
20-23 June		Pre exercise (PRE1) blood samples	91
		Baseline nerve conduction velocity	
25 June	Initiate Exercise I	Initiate air sampling	
29 June	Complete Exercise I	Complete air sampling	
		Post exercise (POST1) blood samples	98
6 July	Initiate Exercise II	Initiate air sampling	
10 July	Complete Exercise II	Complete air sampling	
		Post exercise (POST2) blood samples	110
19 July	Initiate Exercise III	Initiate air sampling	
23 July	Complete Exercise III	Complete air sampling	
		Immediate post exercise blood samples (IPE)	123
31 July-3 Aug		IPE Nerve conduction velocity	
18-21 September		Delayed post exercise (DPE) blood samples	181
		DPE Nerve conduction velocity	

Demographics

The demographic parameters of race, marital status, education, age, smoking status and alcohol consumption were collected on all included in the lead study and medical surveillance populations (n = 63). Figures 2 through 8 illustrate these parameters.

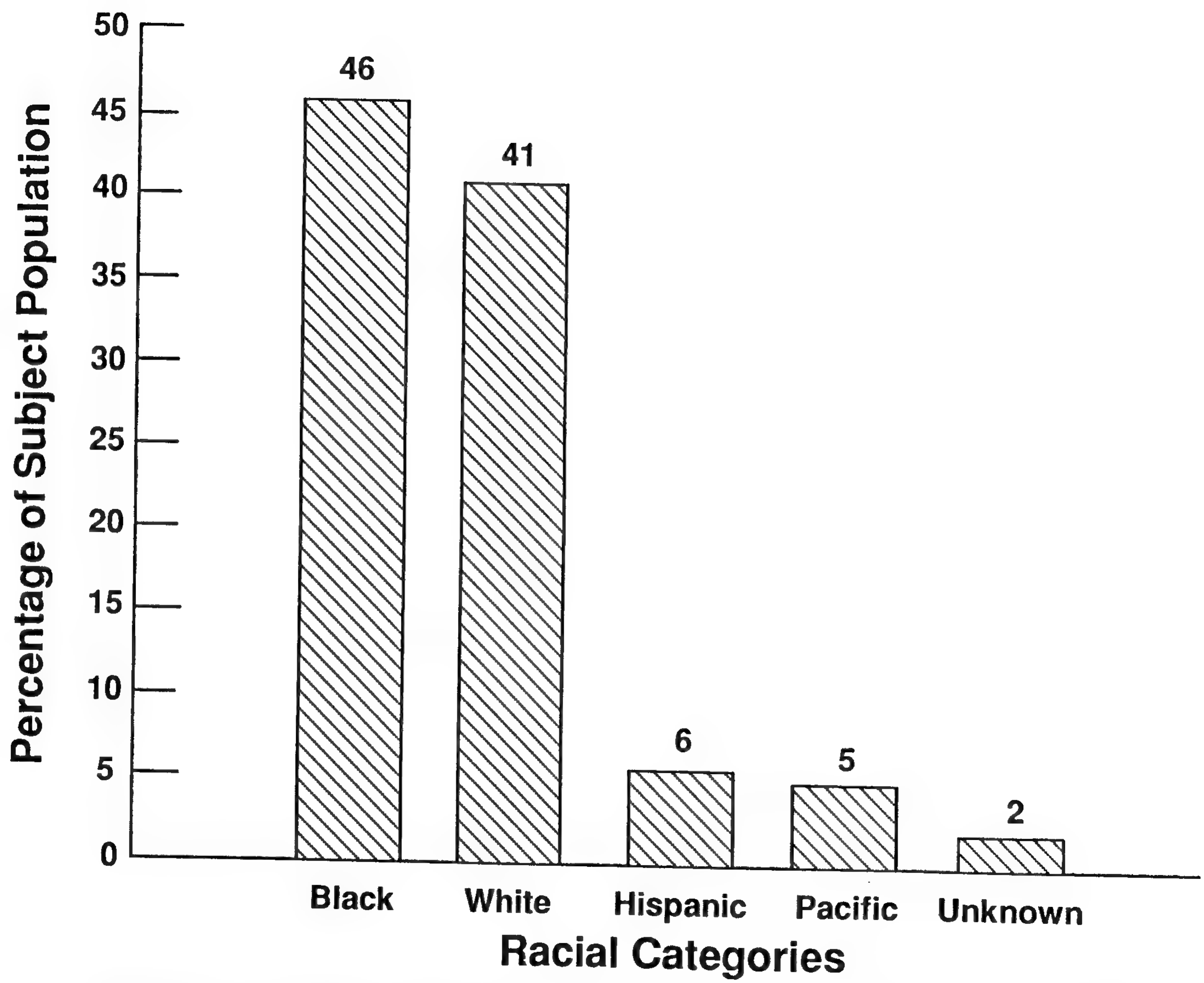

Figure 2. Racial Characteristics of Medical Surveillance Subjects

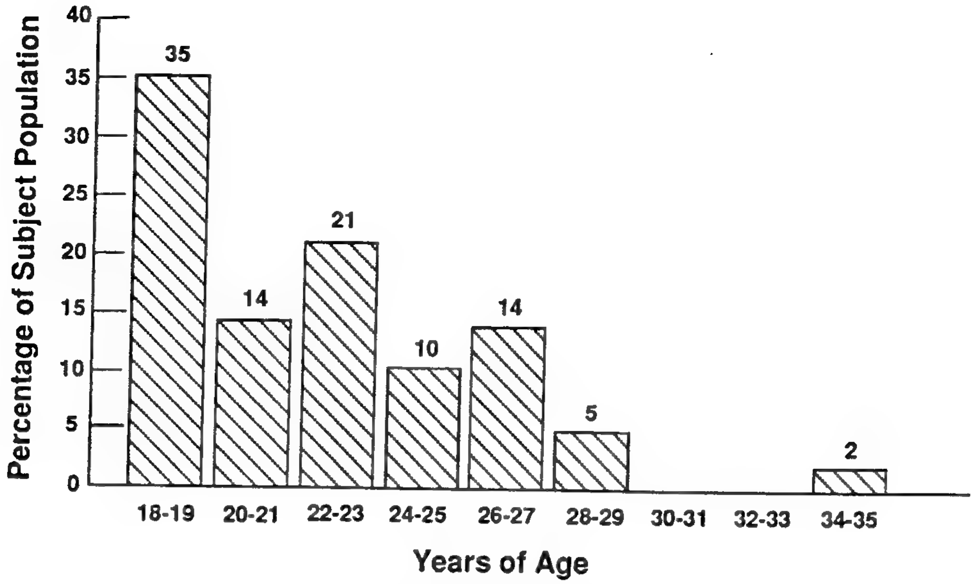

Figure 3. Age Distribution of Medical Surveillance Subjects

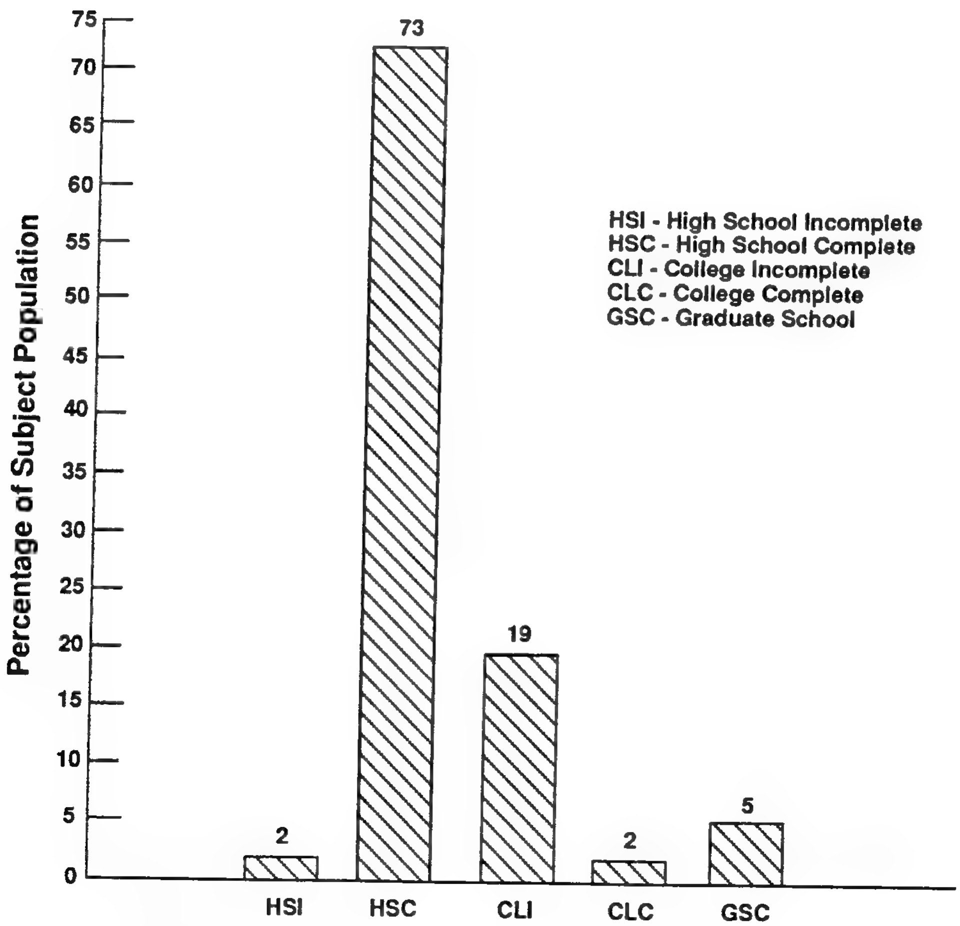

Figure 4. Educational Status of Medical Surveillance Subjects

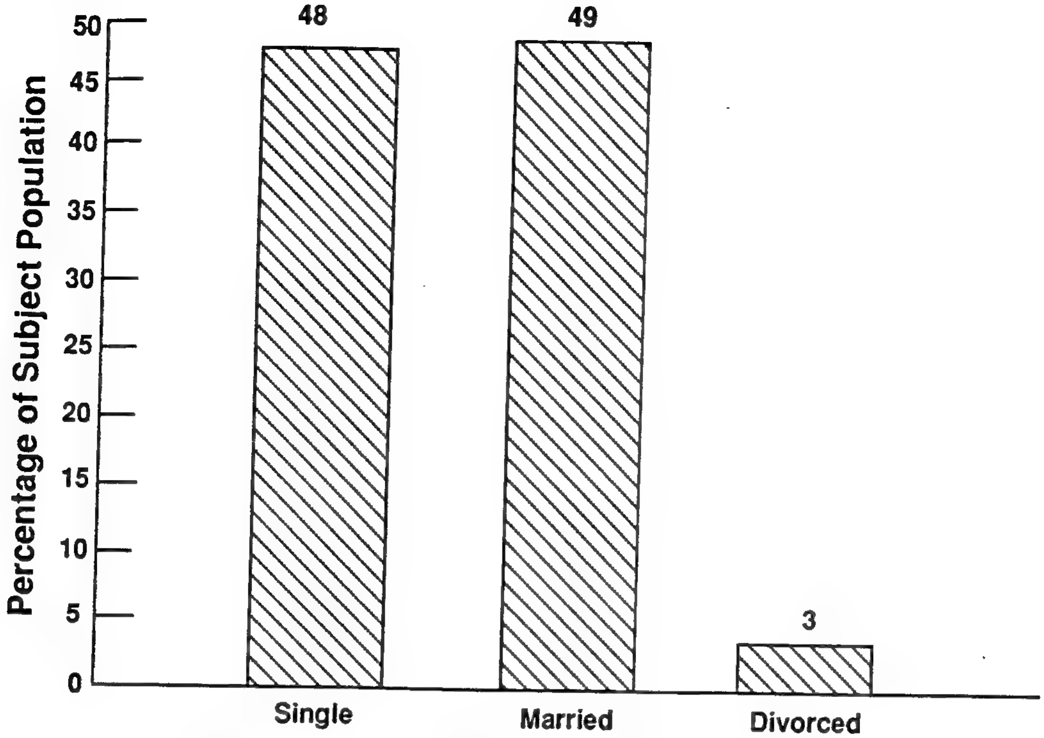

Figure 5. Marital Status of Medical Surveillance Subjects

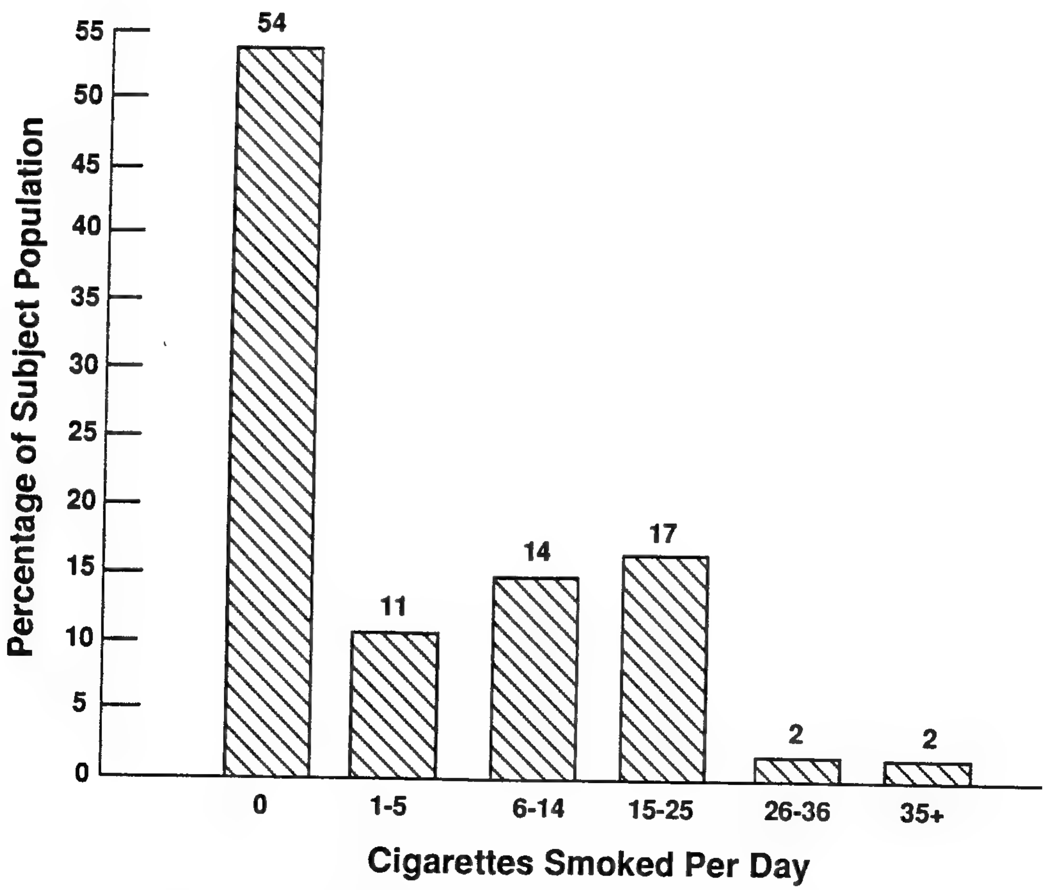

Figure 6. Frequency of Cigarette Smoking by Medical Surveillance Subjects

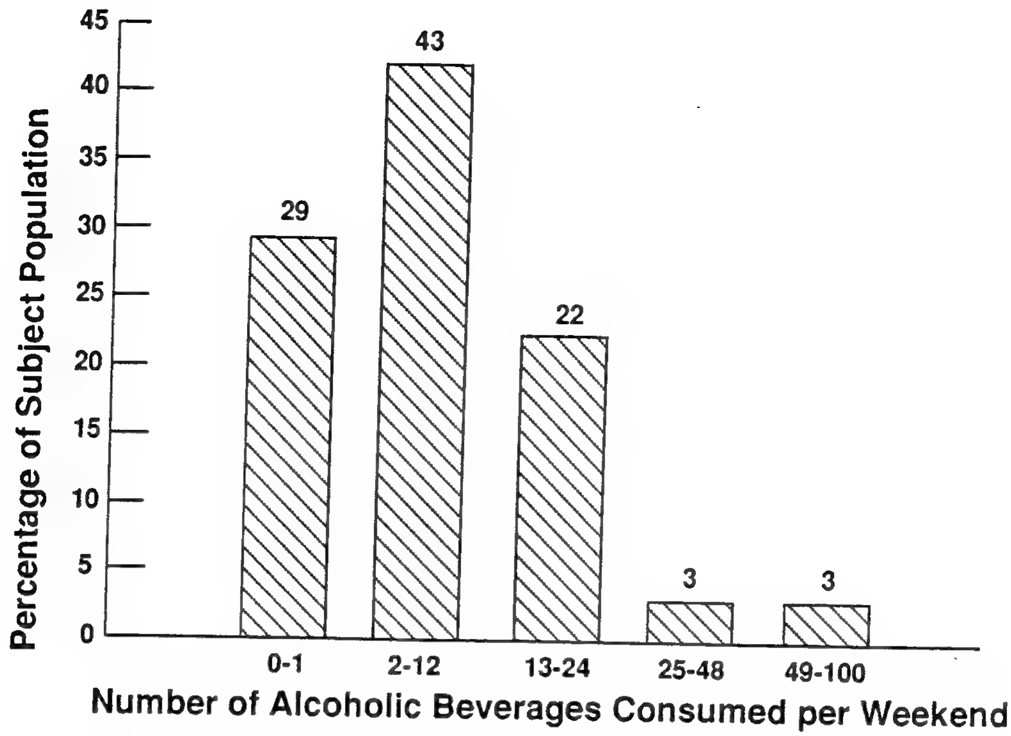

Figure 7. Frequency of Alcohol Consumption by Medical Surveillance Subjects: Weekend Periods

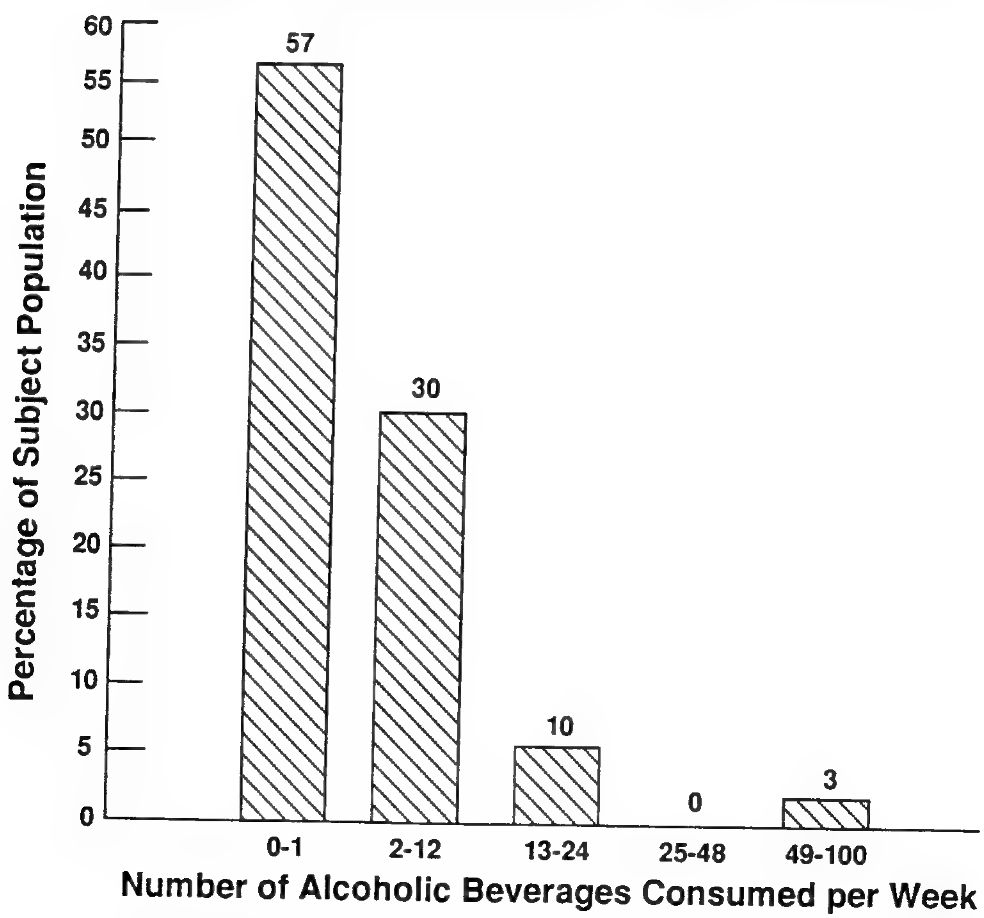

Figure 8. Frequency of Alcohol Consumption by Medical Surveillance Subjects: Weekday Periods

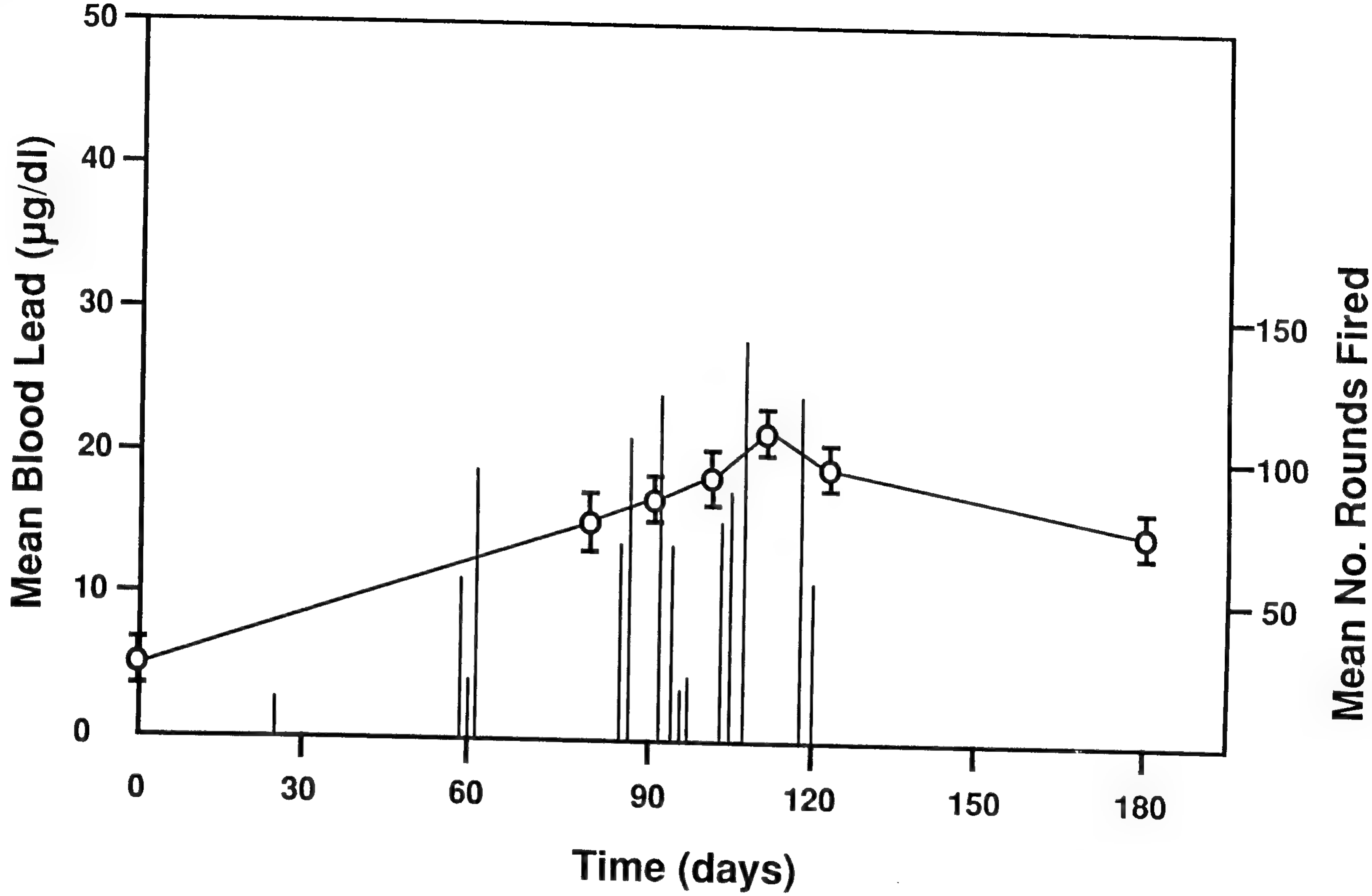

Figure 9. High Zone Rounds Fired and Blood Lead Increase For HIP Crewmen

Previous Exposure History

Previous exposure history was determined for those members of the medical surveillance and lead study populations who were actual gun crew members; resulting in a population of n = 30 for the HIP and n = 33 for the M109A3 (Appendix G, Tables G-1 and G-2). The mean baseline blood lead for the HIP crewmen was 5.5 µg/dl, with an asymmetrical confidence limit of 4.33 - 6.73 µg/dl. The mean blood lead for individuals in the M109A3 group was 4.4 µg/dl (ACL 4.00 - 4.80 µg/dl). The crewmen of the HIP population had a mean blood lead value that was significantly higher than the M109A3 population ($p > 0.05$) (Appendix H, Table H2B). FEP values, on the other hand, were significantly higher at baseline for the M109A3 crew. Questionnaires were examined for all crewmen. Potential factors suggesting reasons for elevated blood lead were examined. These factors included: years of artillery experience, prior military occupation, recent weapons fire exposure, hobbies or occupational activities involving exposure to lead (i.e. welding or soldering), and current medical condition (e.g. anemia). Only two of these factors initially appeared to be important; exposure to artillery emissions in the last six weeks and greater than 5 years experience as an artilleryman.

Prior exposure history for individuals in the HIP population with blood lead concentrations greater than the upper confidence limit of 6.73 µg/dl were compared to these two factors. Five individuals had PbB concentrations above 6.73 µg/dl; all five had been involved in artillery exposure in the last six weeks. Of these five individuals only two had greater than 5 years of artillery experience. Only two individuals had blood lead levels greater than 6.73 µg/dl and recent artillery exposure. In the M109A3 population 16 individuals had PbB greater than the upper confidence limit of 4.80 µg/dl; 10 of these individuals had recent artillery emissions exposure in the last six weeks and two had greater than 5 years artillery experience. Twelve individuals had recent exposure, but did not have blood lead elevated above 4.80 µg/dl.

None of the symptoms reported on the questionnaire were consistent with lead poisoning.

FIRING RECORDS

The number of high zone charges fired during each exposure period, based upon the data base developed by the Field Artillery Board observers is documented in Tables 5 and 6. The number of rounds fired in the Board data base and the artillery battery records were substantially different, especially for the HIP weapons. We chose to use Board records for this study because they provided rounds fired during each period and a record of crewmen activities during firing, whereas DA Form 2408-4 was only for rounds fired in a day and no activities were recorded. We had no independent means of verifying which set of recrods was more accurate. The artillery battery records were always higher than the Board records. The difference ranged from 234 rounds in the pilot and Exercise I periods to a low of 53 rounds in Exercise III for HIPs. For M109A3s, the difference ranged from 340 rounds in the pilot period to 28 rounds in Exercise I.

The round fired data from the board records is graphed as an example in Figure 9 for the two HIP sections that were a part of this study, along with mean blood lead values for each time point and each unit, for comparison.

METEOROLOGY

The influence of wind blowing muzzle emissions back towards gun crews; and back down the gun tube for increased emissions at the breech has been previously reported (see introduction). Quartering winds may also blow emissions from one gun section to another. Besides wind-related factors, airborne lead concentration is expected to be strongly influenced by the number and type of rounds fired and the difference in exposure between gun crews and FAASV crews due to relative proximity to breech emissions. Data available in this study to judge wind-related factors is qualitative and limited. The data was not taken for all periods and was not taken directly at the site of the weapons firing. The qualitative observations and related discussion are provided in Appendix D.

Quartering winds were present in almost all periods, but appeared to be fairly consistent in Exercise II and III for HIPs and Exercise III for A3s. Headwinds were more prevalent for HIPs in Exercise I and for A3s in Exercises I and II.

TABLE 5

High Zone Rounds Fired During the HIP Operational Test: M109A3 Weapons[1]

Firing Period	Date/Time	M109A3 Section A[2]	M109A3 Section D
Pilot Test 1	14 Apr-22 May	70	153
Pilot Test 2	17 June	59	49
	18 June	115	75
	Subtotal:	244	277
Field Exercise I			
Period 1.	25 June/0818	58	58
Period 2.	25 June/1450	8	
Period 3.	25 June/2126	6	6
Period 4.	26 June/0629	46	52
Period 5.	26 June/1426		
Period 6.	26 June/2103		
Period 7.	27 June/0435		
Period 8.	27 June/1257		
Period 9.	27 June/2034	16	16
Period 10.	28 June/0539	40	51
Period 11.	28 June/1446		
Period 12.	28 June/2058		
Period 13.	29 June/0527		
	Subtotal:	174	183
Field Exercise II			
Period 1.	06 July/0557	30	30
Period 2.	06 July/1119	58	18
Period 3.	06 July/1928	36	45
Period 4.	07 July/0323	32	10
Period 5.	07 July/1104	26	
Period 6.	07 July/1848		
Period 7.	08 July/0239		
Period 8.	08 July/0841		
Period 9.	08 July/1631		
Period 10.	08 July/2353	36	9
Period 11.	09 July/0827	50	37
Period 12.	09 July/1704		
Period 13.	10 July/0013		
	Subtotal:	268	149

TABLE 5 (Cont.)

High Zone Rounds Fired During the HIP Operational Test: M109A3 Weapons

Firing Period	Date/Time	M109A3 Section A[2]	M109A3 Section D
Field Exercise III			
Period 1.	19 July/1305	1	22
Period 2.	19 July/1641	31	10
Period 3.	20 July/0111	103	52
Period 4.	20 July/1140	21	21
Period 5.	20 July/1921		
Period 6.	21 July/0200	73	53
Period 7.	21 July/1201	20	
Period 8.	21 July/1854		
Period 9.	22 July/0224		
Period 10.	22 July/1101		
Period 11.	22 July/1933		
Period 12.	23 July/0354		
Period 13.	23 July/1056		
	Subtotal:	249	158
	TOTAL:	935	787

1. Low zone charges were also fired during all periods, but not reported in this table.
2. The high zone charge for the M109A3 during the exercise was the M119A2. The charge includes 3 ounces of lead foil.

TABLE 6

High Zone Rounds Fired During the HIP Operational Test: HIP Weapons[1]

Firing Period	Date/Time	HIP Section B M119[2]	HIP Section B M203[2]	HIP Section C M119	HIP Section C M203
Pilot Test 1	14 Apr	12		7	
	20 May	22		69	
	21 May			19	
	22 May	109		62	
Pilot Test 2	17 June	69		71	
	18 June	112		105	
	Subtotal:	324		333	
Field Exercise I					
Period 1.	25 June/0700	49	41	44	47
Period 2.	25 June/1553	22		22	
Period 3.	25 June/2131	9		9	
Period 4.	26 June/0601	6		72	
Period 5.	26 June/1431				
Period 6.	26 June/2126				
Period 7.	27 June/0545				
Period 8.	27 June/1516				
Period 9.	27 June/2056	17		4	
Period 10.	28 June/0629	10	8	20	8
Period 11.	28 June/1731				
Period 12.	29 June/0231				
Period 13.	29 June/1101				
	Subtotal:	113	49	171	55
Field Exercise II					
Period 1.	6 July/0617		56		1
Period 2.	6 July/1314			9	18
Period 3.	6 July/2021			36	36
Period 4.	7 July/0431	61	25		
Period 5.	7 July/1406				
Period 6.	7 July/2116				
Period 7.	8 July/0416				
Period 8.	8 July/1316				
Period 9.	8 July/2133				
Period 10.	9 July/0501	175		94	
Period 11.	9 July/1422				
Period 12.	9 July/1958				
Period 13.	10 July/1101				
	Subtotal:	236	81	139	55

TABLE 6 (Cont.)

High Zone Rounds Fired During the HIP Operational Test: HIP Weapons

Firing Period	Date/Time	HIP Section B M119[2]	HIP Section B M203[2]	HIP Section C M119	HIP Section C M203
Field Exercise III					
Period 1.	19 July/1502	94		93	
Period 2.	19 July/2301				
Period 3.	20 July/0639	53			
Period 4.	20 July/1321	21		10	23
Period 5.	20 July/2001				
Period 6.	21 July/0547	20	10	20	10
Period 7.	21 July/1158				
Period 8.	21 July/2001				
Period 9.	22 July/0451				
Period 10.	22 July/1156				
Period 11.	22 July/1931				
Period 12.	23 July/0357				
Period 13.	23 July/1016				
	Subtotal:	188	10	123	33
	TOTAL:	1011		909	

1. Low zone charges were also fired during this period, but not recorded in the table.
2. The high zone charge for the HIP during the IOTE included the M119A2, which contains 3 ounces of lead foil; and the M203A1, which contains 5.5 ounces of lead foil.

AIR LEAD CONCENTRATIONS

General

Crewmen from two HIP howitzer sections and from two M109A3 Howitzer sections were chosen arbitrarily for air sample monitoring. The HIP sections were labeled B and C and the M109A3 sections were labeled A and D for the purposes of this study. Following the three exercises, each crewmen was queried as to his position during firing activities. Responses were classified as gunner (G), gunner > 60% of the time (G#), FAASV (F), or FAASV > 60% of the time (F#).

Calculation of Air Lead Concentrations

The rugged physical environment of the field exercises led to several broken pumps and cassettes, pinched hoses, dead batteries and other situations in which an 8-hr collection period for a study subject proved to be unsatisfactory. Criteria were established to determine if certain 8-hr data sets were suitable for estimation of air lead concentrations. These criteria and statistics describing the range of estimated values are listed in Appendix E. Some of the analysis described below used only air concentration data as collected; other analysis used the additional estimated 8-hr concentration data. When estimated data were used in an analysis, the table is marked.

After the lead per filter was determined as described in Materials and Methods above, the sample concentration for each nominal 8-hr sampling period was determined by the following formula:

$Q \text{ X } T_s = V_s$,

$1000\ C_f/V_s \text{ X } 1000 = C_s$, and

$C_s \text{ X } T_s/480 = \text{TWA}$, where

Q = average flow rate (l/min)
T_s = sample time (min)
V_s = sample volume (l)
C_f = Concentration of lead on the filter (mg)
C_s = Concentration of the sample ($\mu g/m^3$)
TWA = 8-hr Time Weighted Average

Compliance with the Permissible Exposure Limit (PEL)

The PEL is established in regulation as 50 $\mu g/m^3$, averaged over an 8-hr period, or alternatively as 400 ÷ hrs worked in a day if exposure exceeds 8 hours in any work day (Ref 11). Since each exercise represented several periods of 72 hrs continuous work, with random intermittent exposure, an alternate PEL may be expressed as 16.7 $\mu g/m^3$. The PEL may also be expressed as 24,000 $\mu g/m^3$-min (60 min/hr X 400 $\mu g/m^3$-hr). Table 7 is a summary of each individual lead exposure study subject's mean 24-hr TWA for each exercise. Except for 4 subjects in Exercise II, all individual exposures were above the PEL of 16.7 $\mu g/m^3$. Table 8 is a summary of each subject's single highest 8-hr TWA, for comparison with the PEL of 50 $\mu g/m^3$. The table also includes each individuals' highest 24-hr TWA for comparison with the alternately computed PEL. All of these computations for Table 8 are based upon actual measured values, without including any estimated values.

Substantial numbers of individuals not only exceeded the 8-hr TWA in each exercise but also exceeded the standard by a considerable margin. Three individuals were at 4 times the PEL in Exercise I, 2 individuals in Exercise II and 6 individuals in Exercise III. More importantly, however, when the most intense exposure for any 24-hr period in any one exercise is computed, all individual exposures exceeded the standard. Twenty-six percent

exceeded the 24-hr standard by a 6-fold margin (Table 8). A summary of Ct product measurements is provided in Appendix F.

Crewman exposures for periods when low zone rounds were fired were assessed (Table 9). Low zone rounds do not contain lead foil in the propellant, but may contain a small amount of lead carbonate or lead styphnate in the primer. Table 9 shows that each individual received only small amounts of measurable lead for each exercise. One period in Exercise I was identified as being responsible for most of the measured lead for the HIP crewmen. Values during this period ranged from 10 - 70 $\mu g/m^3$, which is typical of periods when many rounds are fired. These data suggest that either the round firing data was in error, or that the crew of these weapons had residual rounds which had not been reported and were being fired. Since the period in question was not immediately after a period when high zone rounds were being fired, then questions as to whether the air sampling period had started before firing in the previous period had stopped did not provide an explanation. Previous investigations have raised the possibility that lead measured during periods of low zone firings may be resuspended from floor and wall surfaces of the howitzer, and from soil around the howitzer. There were 158 periods sampled immediately after high zone firing periods. Twenty-five percent of these periods had measurable lead with a mean for these periods of 0.04 $\mu g/m^3$. There were several periods in which most crewmembers received small amounts of detectable lead. Since adjacent howitzers were not firing high zone charges, the source of this lead is unknown.

Data supporting the assessment of number of high zone rounds fired before exceeding the PEL are summarized in Appendix K. Table K-1 illustrates concentration-time products from various studies, including this one, in which 10 rounds or less have been fired. The data for 10 rounds or less in a sampling period should provide the most accurate mean Ct product per round, since the time periods for firing are short and provide fewer opportunities for sampler malfunction, filter clogging and environmental changes. Note in the table that for equivalent number of rounds, the howitzer with the cab filter does not necessarily have the lower Ct product. Also note that except for one sample set, the number of rounds required to equal the PEL is approximately 20 or less. All of these data sets include samples where the number of rounds to equal the PEL is 7 or less. Even the data set for Yuma Proving Ground (Ref 10), without a cab filter, includes samples where the number of rounds to equal the PEL is 20.

TABLE 7

Individual Time-Weighted Average for Each Exercise (Lead Exposure Study Subjects)

Subject #	Sec	Pos	Individual's Mean[1] 24-Hr TWA Exercise I µg/m³	Individual's Mean 24-Hr TWA Exercise II µg/m³	Individual's Mean 24-Hr TWA Exercise III µg/m³
1AB	C	G	118.03	85.19	73.55
2AB	A	G	26.44	40.76	10.29
3AB	D	F#	139.15	93.23	--
4AB	D	G	52.64	121.43*	143.05*
5AB	B	F	74.70*	29.35*	20.73
6AB	A	F	34.55*	--	18.65*
7AB	D	G#	76.19	144.67	122.43
8AB	D	F#	95.13*	97.31	106.15*
9AB	D	G	129.03	144.30*	160.93*
10AB	C	F	84.63	55.01	65.86*
11AB	C	F	57.24	41.31	45.78
12AB	C	G#	98.50	69.50	77.52
13AB	C	F#	58.74*	35.08*	60.43
14AB	A	F	42.99	28.60	22.38
15AB	C	F#	20.98	--	26.91
16AB	B	G	--	46.36*	20.80
17AB	B	F	72.30*	32.07	12.32
18AB	B	F	72.98*	28.59*	12.29*
19AB	C	G	67.09	78.47	72.66*
20AB	A	G	28.88	49.27	55.69*
21AB	C	G	81.57	73.80	66.64
22AB	B	F	64.09	37.17*	14.16*
23AB	D	F	59.75	--	118.97*
24AB	B	G	90.23	39.32	28.98
25AB	C	F	67.29*	57.34	57.15*
26AB	D	F	103.00*	57.05*	75.11
27AB	D	G#	99.65	--	107.22
28AB	B	G	108.92*	92.42	18.66
29AB	A	G	24.32*	28.33	49.19
30AB	B	G	85.56*	55.50	31.21
31AB	A	G	29.66*	50.10	59.39

* one or two 8-hr TWA periods have been estimated, see Appendix E

-- Insufficient or missing data

Based on a mean of five 24-hr periods, even though the last period may have had only one or two 8-hr samples.

TABLE 8
Individual Highest Time-Weighted Average for 8 and 24 Hour Periods

Subject #	Sec	Pos	Individual's Highest 8-Hr TWA Exercise I µg/m³	Individual's Highest 8-Hr TWA Exercise II µg/m³	Individual's Highest 8-Hr TWA Exercise III µg/m³	Individual's Highest 24-Hr Air Lead In Any Exercise µg/m³*min
1AB	C	G	146.13	145.80	212.53	141,847.25
2AB	A	G	50.70	80.53	31.04	43,466.49
3AB	D	F#	234.03	92.48	93.66	183,652.80
4AB	D	G	150.24	134.38	406.01	64,627.46
5AB	B	F	104.69	43.09	62.96	85,586.91
6AB	A	F	51.07	121.01	31.65	73,407.27
7AB	D	G#	251.76	173.10	339.09	182,741.36
8AB	D	F#	145.43	114.21	224.29	152,401.44
9AB	D	G	208.09	231.36	184.46	175,675.20
10AB	C	F	124.11	82.39	144.10	108,304.04
11AB	C	F	92.18	83.56	133.45	94,026.87
12AB	C	G#	125.25	63.40	167.55	124,562.15
13AB	C	F#	106.95	41.55	145.51	94,687.03
14AB	A	F	62.05	41.05	41.26	53,382.05
15AB	C	F#	74.06	ID	61.05	40,522.26
16AB	B	G	107.55	147.57	41.73	96,492.42
17AB	B	F	64.04	62.05	31.34	55,060.22
18AB	B	F	81.70	50.12	10.27	77,520.00
19AB	C	G	108.33	195.28	135.25	103,674.64
20AB	A	G	40.27	62.13	112.05	54,909.84
21AB	C	G	123.43	110.76	169.16	125,052.84
22AB	B	F	93.21	61.53	30.44	54,644.40
23AB	D	F	100.64	NP	276.71	206,794.02
24AB	B	G	97.67	61.79	124.32	96,473.39
25AB	C	F	119.33	112.83	101.11	74,444.83
26AB	D	F	150.68	115.62	105.78	152,592.00
27AB	D	G#	152.74	ID	316.30	187,048.07
28AB	B	G	121.24	334.20	62.72	109,692.44
29AB	A	G	40.56	49.09	92.32	132,764.96
30AB	B	G	82.82	137.97	85.12	96,846.69
31AB	A	G	36.70	82.16	112.64	133,432.44
Highest Indiv TWA			251.76	334.20	406.01	206,794.02
Mean Highest TWA's			111.21	108.15	131.80	108,913.99
Standard Deviation			52.82	65.68	97.95	46,687.34
n			31	28	31	31

ID = Insufficient data; NP = Not Present
Sec - Gun section: A/D, HIPs; B/C, M109A3s
Pos - Vehicle crew position: G=gunner, G#=gunner >60% of the time; F=FAASV; F#=FAASV crewman >60% of the time

TABLE 9

Lead Exposure During Periods When High Zone Charges Were Not Being Fired*
(Mean, $\mu g/m^3$)

Weapons System/ Subject		Exercise I	Exercise II	Exercise III
HIP				
2AB		1.47	5.16	0.00
5AB		15.00	1.47	1.29
6AB		1.46	9.17	0.00
14AB		2.96	7.20	1.45
16AB		8.03	2.27	1.29
17AB		14.94	2.98	0.00
18AB		13.42	4.55	0.00
20AB		2.94	8.24	1.52
22AB		8.49	4.57	1.28
24AB		7.11	2.42	0.00
28AB		16.06	3.37	0.00
29AB		0.00	5.22	0.00
30AB		7.39	2.31	0.00
31AB		0.00	5.09	0.00
	Mean	7.09	4.58	0.49
	SD	5.86	2.34	0.68
M109A3				
1AB		5.92	4.45	2.64
3AB		6.39	1.75	13.38
4AB		1.28	0.00	0.00
7AB		1.31	3.46	7.34
8AB		0.00	5.12	0.00
9AB		6.51	1.71	9.00
10AB		4.50	2.96	2.67
11AB		2.89	5.87	2.63
12AB		4.41	--	2.62
13AB		7.43	1.45	1.30
15AB		2.96	0.00	1.32
19AB		2.93	2.88	3.89
21AB		0.00	1.48	0.00
23AB		1.29	--	1.44
25AB		1.49	2.91	3.95
26AB		5.14	0.00	16.37
27AB		0.00	0.00	0.00
	Mean	3.20	2.27	4.03
	SD	2.48	1.91	4.81

*Estimated data has been used in the preparation of this table, see Appendix E

Comparison of Air Lead Exposure between Types of Weapons, Sections and Types of Vehicles

The 8-hr TWA of 33.37 µg/m^3 for M109A3 crewmen was significantly higher than the exposure TWA of 16.95 µg/m^3 for HIP crewmen when the data for all three exercises were combined (Table 10). There did not appear to be any overall differences between the three exercises for exposures to the M109A3 crewmen; however there was an overall difference between exercises for the HIPs (Appendix H, Table H-1).

The mean exposure of 32.99, 33.32 and 33.83 µg/m^3 for M109A3 crewmen was significantly higher during exercises I, II and III respectively, than for the HIP crewmen (HIP exposure levels were 22.36, 16.76 and 11.29 µg/m^3) (Table 10).

Gun vehicle crewmen experienced higher exposures than FAASV crewmen for HIPs during exercises II and III, and for M109A3s during Exercise II (Table 11).

When exposures to crewmen in vehicles side by side in the same battery were considered, HIP Section C was significantly higher at 15.79 µg/m^3 during exercise III than Section B (8.07 µg/m^3), but just the opposite was true during exercise I. There was no significant difference between the Sections for HIPs during exercise II. Section A of the M109A3 Battery was significantly higher during exercises II and III than Section D (Table 12).

As mentioned previously, air lead concentration can be affected by the number of rounds fired, the meteorology, physical configuration of the crew space and operation of the ventilator. In particular, differences between the two types of howitzer include a filter on the ventilator for the HIP and a muzzle brake which directs emissions more directly back towards the cab. The HIP also fires two different types of high lead rounds, whereas the M109A3 fires only one.

Certain qualitative comparisons can be made with an understanding of these differences between types of howitzer and with the round and meterology data provided previously. First, one would suspect that the howitzer which fired the highest number of rounds would have the highest crew exposures. However despite the HIP firing 203 more rounds (based on Board records - Tables 5 and 6) for the combined exercises, the M109A3 crew had the higher exposure (Table 10). When the same relationship was examined for Exercises I and II, the HIP system with the higher round total, had the lower exposure. In Exercise III, the M109A3 had the higher round total and the higher exposure. When two sections of the same system are compared, there was a clear pattern of the relationship between round and exposure concentration in 4 out of 6 exercises. HIP section C had the higher round total (Tables 5 and 6) and the higher exposure during Exercise I (Table 12), Section B had the higher round total and exposure level during Exercise III, while the data for exposure from Exercise II was inconclusive, despite section B having the higher round total. The pattern for the M109A3 was similar, as Section A had both the higher exposure and the higher round total for Exercises II and III (The exposure pattern for exercise I was inconclusive, despite section D having the higher round total).

TABLE 10
Comparison between HIPs and M109A3s for Mean 8-Hr TWA and Comparison between HIPs and M109A3s for Mean 8-Hr TWA, by Exercise

Effect	8-Hr TWA mean[1]	SE	n	F / p
Weapons System				
HIPs	16.95	1.481	38	74.74
A3s	33.37	1.882	43	0.0001*
Field Exercise I				
HIPs	22.36	3.031	13	7.18
M109A3s	32.99	2.595	16	0.0124*
Field Exercise II				
HIPs	16.76	1.775	13	15.97
M109A3s	33.32	3.865	12	0.0006*
Field Exercise III				
HIPs	11.29	1.815	12	26.17
M109A3s	33.83	3.652	15	0.0001*

*$\alpha = 0.05$
[1]Estimated data has been used in the preparation of this table, see Appendix E

TABLE 11
Difference Between FAASV and Gun Mean 8-Hr TWA, by Weapons System, by Field Exercise

Field Exercise	FAASV			Gun				
	mean[1]	SE	n	mean	SE	n	F	p
HIPs								
Exercise I	23.18	2.710	6	21.65	5.357	7	0.06	0.8139
Exercise II	12.14	0.463	5	19.65	2.367	8	6.00	0.0323*
Exercise III	6.79	0.738	5	14.50	2.441	7	6.65	0.0275*
M109A3s								
Exercise I	31.24	3.959	8	34.75	3.507	8	0.44	0.5180
Exercise II	25.61	3.269	6	41.02	5.594	6	5.66	0.0387*
Exercise III	27.21	4.573	7	39.62	4.907	8	3.35	0.0900

*$\alpha = 0.05$
[1]Estimated data has been used in the preparation of this table, see Appendix E

TABLE 12

Comparison Between Sections for Mean 8-Hr TWA, by Weapons System, By Field Exercise

Field Exercise	Section B (HIP) Section D (M109A3) mean[1]	SE	n	Section C (HIP) Section A (M109A3) mean	SE	n	F	p
HIPs								
Exercise I	11.98	1.059	6	31.25	2.181	7	56.55	0.0001*
Exercise II	14.24	1.609	5	18.34	2.632	8	1.29	0.2802
Exercise III	15.79	3.294	5	8.07	1.021	7	6.67	0.0273*
M109A3s								
Exercise I	30.04	2.982	8	35.95	4.178	8	1.33	0.2685
Exercise II	24.14	2.274	6	42.50	5.182	6	10.52	0.0088*
Exercise III	23.95	1.916	9	48.64	3.381	6	46.97	0.0001*

*$\alpha = 0.05$

[1]Estimated data has been used in the preparation of this table, see Appendix E

BLOOD PARAMETERS

General

It had been hoped to establish baseline values for all test participants prior to the training phase of the IOTE. Initial blood samples were taken over the period 20 - 25 March 1989 to measure four parameters: blood lead, hematocrit, hemoglobin and free erythrocyte protoporphyrin (FEP). Due to personnel reassignments, duty changes, etc. additional "baseline" samples were taken on 8 June after the training phase had been completed. With there being no common baseline time point, PRE1 blood samples were taken from test subjects on 23 June. These pre-test blood samples were also taken to coincide with the first opportunity that we had to measure nerve conduction velocity. For most analyses however, those individuals with only an 8 June base line sample were dropped because their population size was so small. The mean 8 June value for A3 crewmen was 9.7 µg/dl (SD = 1.2, n = 3) and for the HIP crewmen was 14.7 µg/dl (SD = 7.8, n = 9).

Following the pre-exercise training and pilot tests, blood lead levels increased to a mean of 15.4 µg/dl (PRE1). Further increases were seen after the first two exercises (POST1: mean 20.2 µg/dl; POST2: mean 23.4 µg/dl). These increases were 205, 287 and 367% above baseline. Despite continued exposure during the third exercise, blood lead levels dropped to 21.3 µg/dl. Approximately eight weeks after the last exposure, blood lead levels had dropped to 13.4 µg/dl, a figure still more than twice the initial baseline value. None of the individuals in this study had PbB values above 40 µg/dl (Appendix G, Tables G-1 and G-2), which is used in the OSHA standard as a threshold for monitoring the employee every six months and for employee notification. Twelve soldiers had blood lead values equal to or in excess of 30 µg/dl, which is the level at which OSHA requires that individuals be provided advice on the reproductive hazards of lead exposure. Two of this group were at or above

30 µg/dl for two consecutive sampling periods. All of the sections and the 7 most highly exposed individuals achieved a reduction of 1/2 of blood lead between IPE and DPE (58 days); the 6 individuals with the highest blood lead values (all M109A3 crewmen) lagged slightly behind and did not reach $t_{1/2}$ by the DPE time point. Lead increases for both HIP and M109A3 crewmen (medical surveillance population) were statistically significant between BL and IPE; as were lead declines between BL and DPE (Table 13).

Mean FEP decreased for the group between the BL measurement and PRE1 measurement; climbing gradually through POST1, POST2 and IPE; and falling again at eight weeks post-exposure. Only one HIP crewman exceeded the CDC recommended limit of 35 µg/dl for FEP at baseline, while 8 M109A3 crewmen exceeded the limit at baseline (Appendix G, Tables G-1 and G-2). Six other HIP crewmen exceeded the limit at some other time period during the study; most at POST2 or IPE. In contrast 13 soldiers serving as M109A3 crewmen had elevated FEP, again most at POST2 or IPE. Five M109A3 crewmen had more than one elevated value.

When PbB and FEP are plotted against time for each of the four sections being studied, M109A3 sections A and D and HIP section B showed an increase at POST1, with continued FEP increase at IPE (123 days after the start of the exercise), despite dropping PbB values. The FEP increase at IPE is an illustration of the "lag" effect often seen with this endpoint (Figures 10 and 11). HIP section C did not demonstrate such a lag effect, while HIP section B had periods of increases and decreases during the exercises. These HIP sections also had the lowest mean exposure of the groups studied. Blood lead and FEP were also plotted for the 7 individuals with the highest mean air lead exposures (all M109A3 crewmen); again FEP is seen to lag at IPE (Figure 12). Blood lead and FEP were plotted for 6 individuals with the highest peak blood lead (all M109A3 crewmen); the lag in elevated FEP was seen at both IPE and DPE (Figure 13). Eleven out of 16 (69%) M109A3 crewmen (lead exposure study subjects) had an FEP increase between POST2 and IPE, while 7 out of 30 (23%) (including medical surveillance subjects) M109A3 crewmen had an FEP increase between IPE and DPE (123 to 181 days). Nine out of 14 (64%) HIP crewmen (lead exposure study subjects) had an FEP increase between POST2 and IPE, while none had an increase by the DPE time point (Appendix G, Tables G-1 and G-2). FEP increased sooner and at a lower blood lead value for the HIP sections (at 91 days and mean PbB of 16.35 µg/dl) than for the M109A3 sections, the 7 most highly exposed individuals or the 7 individuals with the highest peak PbB (at 98 days and mean PbB of 20.7 µg/dl). FEP for HIP crewmen (medical surveillance population) was significantly higher at IPE than at BL; but at DPE was not different than BL. DPE proved to be significantly lower than IPE (Table 13).

Hematocrit values fell below the reference value of 42% (Ref 18) at PRE1 for HIP crewmen, increasing to 29 and 43% Hct respectively at POST1 and POST2. Hematocrit values were essentially at baseline at IPE and DPE. Twenty percent of M109A3 crewmen were below 42% Hct at baseline, which subsequently had fallen to zero by PRE1, increased to a maximum of 29% at POST1 and declined to 13% and 9% Hct at POST2 and IPE respectively, both of which were smaller decreases than for the HIP crewmen (Appendix G, Tables G-1 and G-2). DPE was essentially at zero by DPE. Hematocrit levels at each time point were indistinguishable from each other statistically for both M109A3 and HIP crewmen (medical surveillance population)(Table 13).

Hemoglobin changes were similar to Hct changes. Hb values less than 14 g/dl increased steadily through POST2, peaking when 36% of HIP crewmen were below the reference value (Ref 19). Thirteen to 14% of crewmen remained below 14 g/dl during IPE and DPE. Thirteen percent of M109A3 crewmen were below the reference value at BL, increasing to 29, 25 and 21% at POST1, POST2 and IPE respectively, before falling to 3% at DPE (Appendix G, Tables G-3 and G-4).

Comparison of Blood Sample Parameters Between Types of Weapons, Sections and Types of Vehicles for the Medical Surveillance Population (3 time points)

Results indicate an overall time effect (difference among the three time measurements, BL, IPE, and DPE) for crewmen blood values of HIPs and M109A3s for both PbB and FEP, and of HIPs for Hematocrit. There was a marginally non-significant time effect for M109A3s for Hematocrit (Appendix H, Table H-2A).

PbB

Analysis of variance showed that there was a significant difference between HIP and M109A3 crewmen at the baseline measurement and not at IPE or DPE. With a mean value of 5.5 µg/dl, BL value for HIP crewmen, this difference is compared to the M109A3 mean value of 4.4 µg/dl (Table 13).

There was a significant difference in the rate of PbB increase for the BL --> IPE time points between weapons systems, with the higher rate present in the M109A3s. The rate of PbB decrease was not different between weapons systems for IPE --> DPE (Appendix H, Table H-2B).

For the HIPs, there were differences between sections B and D mean PbBs at BL, while no differences existed at IPE and DPE. A3 section mean differences for sections A and D were found at IPE, but not at BL or DPE (Appendix H, Table H-2E). HIP section D (not in lead exposure study population) had the highest mean PbB at BL, while A3 section A (same as lead exposure study section A) had the highest mean PbB. When all sections were combined, regardless of weapons system, slope comparisons for sections for each of the time periods showed no differences. When examined by individual weapons system, differences in the slope of PbB change between sections were present for A3s in the time period BL --> IPE. A3 section A had the steepest slope, followed by B, C, and D (Appendix H, Table H-2D).

Free Erythrocyte Protoporphyrin (FEP)

When crewmen FEP values for HIPs and M109A3s were compared, a significant difference existed at the baseline measurement. Baseline FEP values for the M109A3 crewmen were 30.3 µg/dl and for the HIP crewmen were 19.5 µg/dl (Table 13). There was also a significant difference at DPE, with the HIP crewmen continuing to show a lower value than the M109A3 crewmen.

In examining the slopes of changes between the timepoints and between weapons systems, the comparisons for FEP paralleled data presented for PbB for the time period BL --> IPE; i.e., there was a significant difference between the two weapons systems and FEP values for HIPs were increasing. These differences were not found in comparisons between HIPs and M109A3s from IPE --> DPE, although FEP values for both units were decreasing (Appendix H, Table H-2B).

There were no differences between any of the sections at each of the time points, when examined by weapons system (Appendix H, Table H-2E). There were no differences in FEP rate of change when the combined HIP sections were compared with the combined A3 sections for each of the time periods (Appendix H, Table H-2D).

Hematocrit

M109A3 crewmen had lower hematocrit values at BL than HIP crewmen (Table 13). When slopes are examined for differences between weapons systems, hematocrit rate of change was different BL --> IPE and BL --> DPE Since there were no differences IPE --> DPE, the changes observed for BL --> DPE is a function of the change BL --> IPE. Hematocrit values fell for HIPs from BL --> IPE and BL --> DPE and increased for M109A3s across all time points (Appendix H, Table H-2B).

There were no significant differences for any of the HIP sections at any of the time points for Hct. A3 differences between sections A and B (section B was not a part of the lead study population) existed at IPE. Slope comparisons among sections for hematocrit showed an overall difference in rate of change for the BL --> IPE measurements for M109A3 sections (two sections increased and two sections decreased (Appendix H, Table H-2D) and no significant changes for HIPs.

TABLE 13

Comparisons Among Times, By Weapon System, for Each Blood Parameter, and Comparison Between Weapons Systems, at Each Time, for Each Blood Parameter (Medical Surveillance Subjects)

Blood Parameter	HIPs				M109A3s				F	p[3]
	Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	n	Scheffe[2] Grouping	Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	n	Scheffe[2] Grouping		
PbB[4]										
BL	5.5	(4.33, 6.73)	20	C	4.4	(4.00, 4.80)	27	C	5.13	0.0287*
IPE	20.1	(17.94, 22.44)	20	A	23.0	(20.41, 25.69)	27	A	2.46	0.1244
DPE	11.9	(9.92, 14.02)	12	B	12.8	(11.35, 14.26)	25	B	0.37	0.5461
FEP										
BL	19.5	(17.58, 21.49)	20	B	30.3	(22.58, 33.76)	27	AB	30.32	0.0001*
IPE	29.8	(27.17, 32.62)	20	A	31.9	(28.98, 34.69)	27	A	0.72	0.4011
DPE	19.4	(17.09, 21.89)	12	B	24.1	(22.00, 26.28)	25	B	6.69	0.0144*
Hematocrit										
BL	46.3	(45.48, 47.14)	20	A	43.9	(43.10, 44.72)	27	A	17.99	0.0001*
IPE	44.7	(43.59, 45.75)	20	AB	44.6	(43.40, 45.77)	27	A	0.16	0.6874
DPE	45.4	(43.71, 47.16)	12	AB	45.3	(44.49, 46.07)	24	A	0.69	0.4124

[1]Means and upper and lower 95 percent asymmetrical confidence limits are backtransformed.
[2]Scheffe's Multiple Comparison Procedure. Means with the same letter in each column are not different from each other.
[3]α=0.05.
[4]PbB-blood lead (μg/dl); FEP-free erythrocyte protoporphyrin (μg/dl); Hct-hematocrit (%)

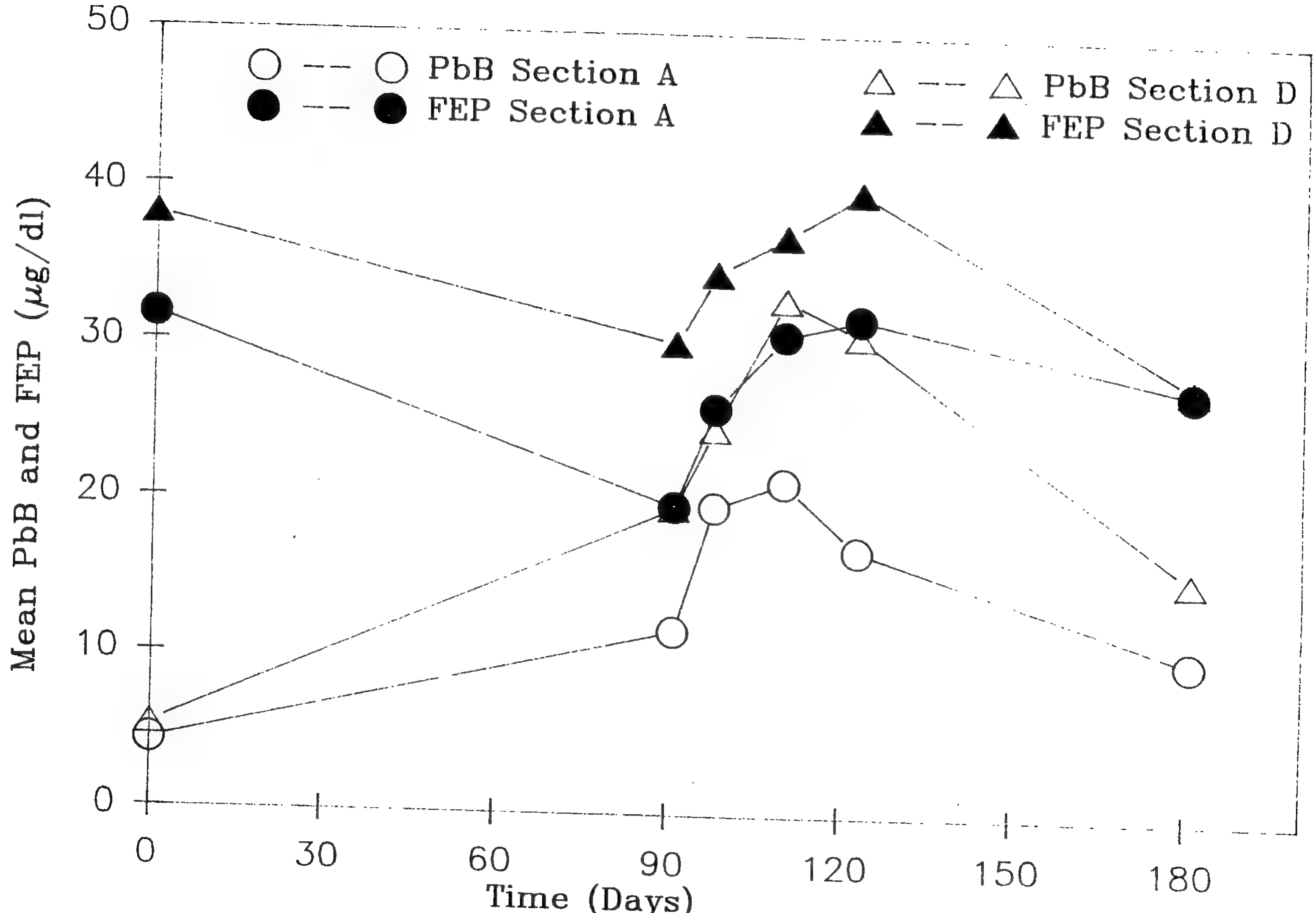

Figure 10. Blood Lead and Free Erythrocyte Protoporphyrin Changes With Time for M109A3 Crewmen

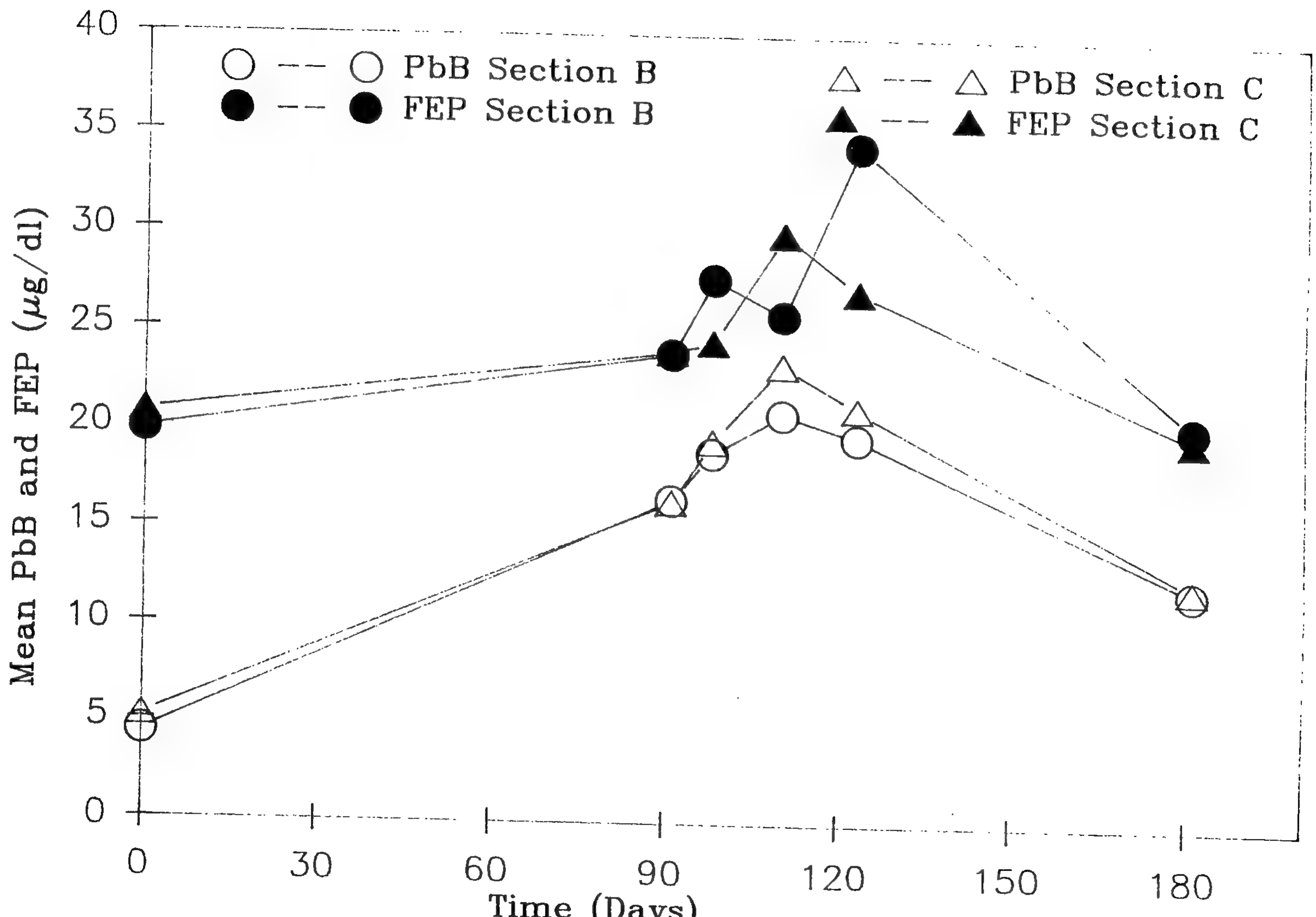

Figure 11. Blood Lead and Free Erythrocyte Protoporphyrin Changes With Time for HIP Crewmen

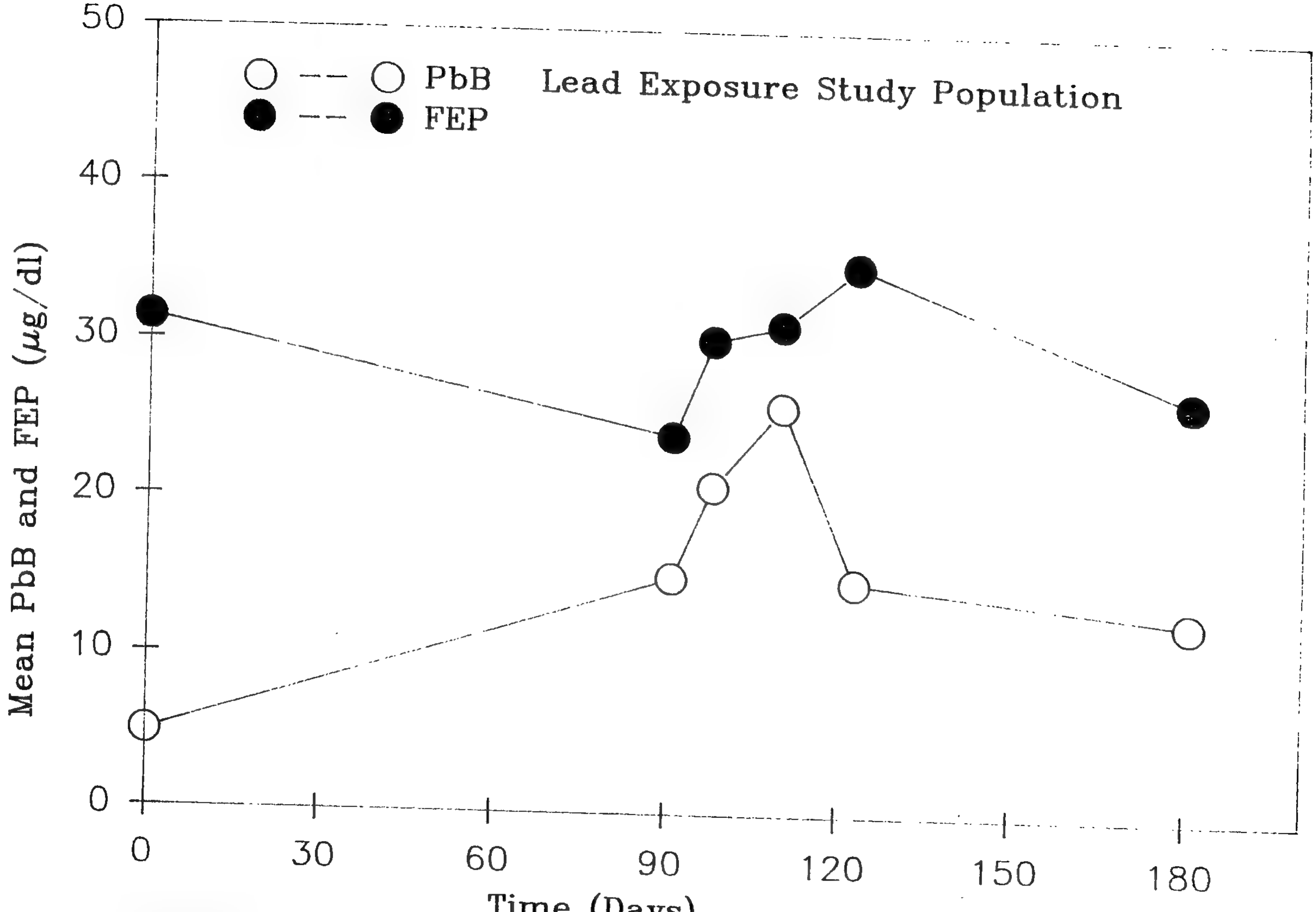

Figure 12. Blood Lead and Free Erythrocyte Protoporphyrin for 7 Individuals with the Highest Air Lead Exposure

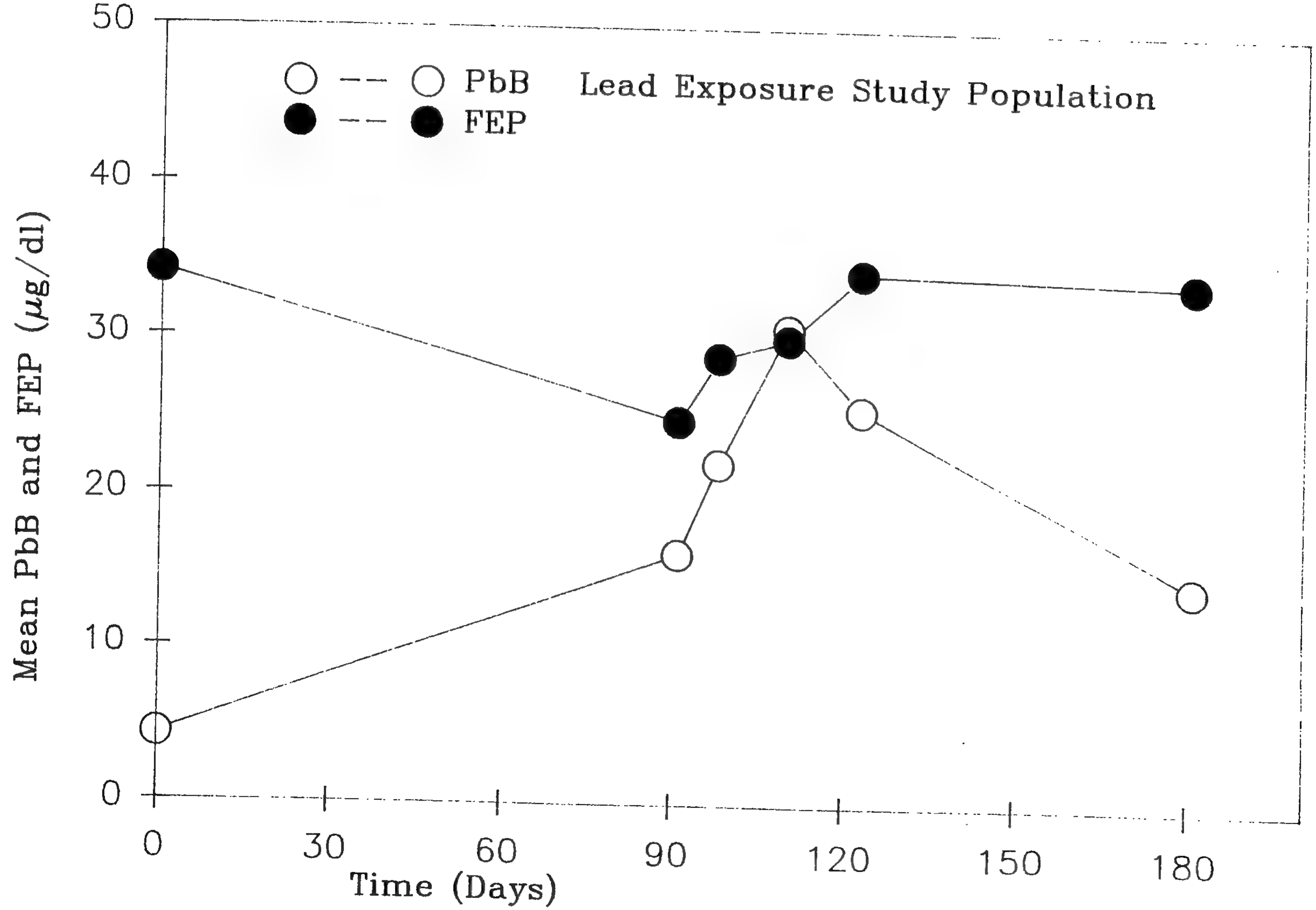

Figure 13. Blood Lead and Free Erythrocyte Protoporphyrin for 6 Individuals with the Highest Peak Blood Lead

Comparison of Blood Lead Changes with Time for Types of Weapons and Sections for the Lead Study Subject Population (6 time points)

Since there was no overall weapons system effects between the HIP and the M109A3 in blood lead values ($F=0.02$; $p=0.8990$) (Appendix H, Table H-3B) and in the interaction between weapons system and time ($F=1.17$; $p=0.3275$) (Appendix H, Table H-3A), the values were pooled for further analysis (BL --> IPE only). The difference between every time period except POST2 --> IPE was significant for the pooled data. The time period differences for HIPs were significant at BL --> PRE1, BL --> POST1, BL --> POST2, and PRE1 --> POST2 (and for the overall time period BL --> DPE) (Appendix H, Table H-3D). M109A3 differences were significant at every time period except POST2 --> IPE (Appendix H, Table H-3C).

When these time differences were examined for HIP sections, they were significant at BL --> PRE1, BL --> POST1 and BL --> POST2 for Section B; and at BL --> PRE1, BL --> POST1, BL --> POST2, PRE1 --> POST1(marginally non-significant), and PRE1 --> POST2 (also marginally non-significant) for Section C (Appendix H, Table H-3E). A similar examination of M109A3 sections identified significant differences at each time period except POST1 --> POST2 and POST2 --> IPE for both sections (Appendix H, Table H-3F).

These data for the change in blood lead identify that major changes over the various time periods were concentrated in the pre-exercise firing period for the HIP when pilot testing was occuring, with smaller but still significant increases during the first two exercises. The data for the M109A3s also show that a significant proportion of the increase was in the pilot phase exposures, however additional increases during the PRE1 --> POST2 period depended upon section. Neither weapons system had significant additional blood lead increases in the POST2 --> IPE period.

NERVE CONDUCTION VELOCITY MEASUREMENTS

Raw data tables for baseline (BL), immediate post exposure (IPE) and delayed post exposure (DPE) skin temperatures; BL, IPE and DPE NCV's (without temperature correction; and IPE and DPE temperature corrected NCV's are in Appendix I.

Limb temperature differences between BL and IPE and DPE measurements were corrected by the method of de Jesus (Ref 16). An objective established prior to the study was to bring hand temperatures to 34°C and leg temperatures to 33°C. The mean hand temperature was 33°C and the mean leg temperature was 32°C; additionally IPE and DPE individual temperature values were not more than 1°C different from BL. Measurement error was also quite low (largest value of SE = 1.1 m/s).

The individual differences between BL and IPE (Appendix I, Table I-6) demonstrated a mean decrease (not temperature adjusted) of 1.2 m/sec for the sural sensory nerve that was statistically significant ($p<0.01$) (Table 14), and a mean decrease of 0.9 m/sec for the peroneal motor nerve appeared that was marginally non-significant ($p<.1$).

When temperature adjusted IPE values were used for the paired t-test (Appendix I, Table I-8), the mean decrease for the peroneal motor nerve was 1.2 m/sec with a $p<0.025$, and the decrease for the sural sensory nerve was 0.5 m/sec with a $p<0.2$ that was not significant (Table 14). In addition, a small increase in mean NCV value appeared for the ulnar sensory nerve (1.2 m/sec, $p<0.05$).

Like measurements and comparisons were made at the DPE time point. With the data set not temperature corrected, statistically significant mean decreases of 1.7 m/sec and 1.0 m/sec appeared for the sural sensory and the peroneal motor nerves, respectively ($p<0.005$ and 0.025) (Table 15). A mean decrease of 0.7 m/sec appeared for the median sensory nerve that was borderline in significance ($p<0.1$). When temperature-adjusted DPE values (Appendix I, Table I-9) were used for the paired t-test, the mean decrease for the sural sensory nerve was still 1.7 m/sec and that for the peroneal motor nerve decreased to 1.5 m/sec; both changes increased in level of statistical significance (Table 15). No other nerve showed a statistically significant change in NCV.

For both the peroneal motor and the sural sensory nerves the magnitude and the statistical significance of the NCV decreases were greater during the post exposure period. Futher analysis of the data for the change in NCV value during the IPE to DPE (not temperature corrected) period showed a mean negative change for each nerve (Appendix I, Table I-10). In the case of the ulnar motor (UM) and sural sensory (SS) nerves, the mean

decrease was statistically significant from zero ($p < .025$), while the US nerve approached borderline in significance (Table 16). The magnitude of the decrease in NCV was about 1 m/sec for the latter nerves.

TABLE 14

Statistical Analysis of Baseline to Immediate Post-exposure Changes in NCV Values (m/sec) for Each Nerve by the t-test for Paired Comparisons

	ΔMM	ΔUM	ΔMS	ΔUS	ΔPM	ΔSS
	Without IPE temperature adjustment					
Mean	0.00	0.63	-0.40	0.14	-0.90	-1.18
SD	2.39	2.04	2.07	2.76	2.46	2.13
SE	0.45	0.39	0.39	0.53	0.47	0.42
n	28	28	28	27	28	26
t	0	1.620	1.023	0.258	1.928	2.814
p	--	<0.200	<0.400	--	<0.100	<0.010
	With IPE temperature adjustment					
Mean	0.13	0.75	0.61	1.24	-1.17	-0.51
SD	2.71	2.31	2.28	2.77	2.52	1.94
SE	0.51	0.44	0.43	0.53	0.48	0.38
n	28	28	28	27	28	26
t	0.244	1.730	1.407	2.320	2.457	1.333
p	--	<0.100	<0.200	<0.050	<0.025	<0.200

[1]A negative mean value indicates a decrease in NCV from BL to IPE.

$$t = \frac{\bar{x}\,(4NCV) - 0}{SD/N}$$

TABLE 15

Statistical Analysis of Baseline to Delayed Post-exposure Changes in NCV Values (m/sec) for Each Nerve by the t-test for Paired Comparisons

	ΔMM	ΔUM	ΔMS	ΔUS	ΔPM	ΔSS
Without DPE temperature adjustment						
Mean	-0.3	-0.7	-0.7	-0.5	-1.0	-1.7
SD	2.8	2.5	2.1	3.2	2.1	2.4
SE	0.5	0.5	0.4	0.6	0.4	0.5
n	27	27	27	25	27	26
t	0.557	1.455	1.732	0.781	2.474	3.612
p	--	<0.2	<0.1	<0.5	<0.025	<0.005
With DPE temperature adjustment						
Mean	-0.3	-0.6	-0.3	0.2	-1.5	-1.7
SD	2.6	2.4	2.6	2.4	2.4	2.3
SE	0.5	0.5	0.5	0.5	0.5	0.4
n	27	27	27	25	27	26
t	0.600	1.299	0.600	0.417	3.248	3.769
p	--	<0.400	--	--	<0.050	<0.001

[1]A negative mean value indicates a decrease in NCV from BL to DPE.

TABLE 16

Statistical Analysis of Immediate Post-exposure to Delayed Post-exposure Changes in NCV Values (m/sec) for Each Nerve by the t-test for Paired Comparisons

	ΔMM	ΔUM	ΔMS	ΔUS	ΔPM	ΔSS
Mean	-0.03	-1.23	-0.82	-1.13	-0.63	-0.95
SD	2.01	2.28	2.85	3.21	2.85	1.71
SE	0.39	0.45	0.56	0.65	0.57	0.34
n	26	26	26	24	25	25
t	0.076	2.750	1.457	1.718	1.109	2.776
p	--	<0.025	<0.200	<0.100	<0.300	<0.025

Separation of the data by weapon system shows that the relative standard deviations (RSD = SD/mean) of the mean decreases for the UM and SS nerves are smaller for the M109A3 crew member values than for the HIP crew member values (Table 17). From these results, it appears that NCV decreases for these nerves in the IPE to DPE time period were statistically significant for the A3 crew members but not the HIP crew members.

Group means between HIP and A3 crew members were analyzed by t-test. The means were not significantly different for any of the three periods.

TABLE 17

Mean Differences in Nerve Conduction Velocity (NCV) from IPE to DPE for Crew Members Firing the A3 vs. the HIP 155mm Howitzer[1]

	MM		UM		MS		US		PM		SS	
	A3	HIP	A3	HIP	A3	HIP	A3	HIP	A3	HIP	A3	HIP
Mean	-0.29	0.10	-1.70	-1.72	0.41	-1.35	-0.51	-1.51	-0.61	-0.40	-0.97	0.10
SD	1.59	2.29	1.30	3.02	3.23	2.84	4.06	2.98	2.32	3.30	1.28	1.54
SE	0.50	0.76	0.41	1.00	1.04	0.95	1.28	0.94	0.73	1.10	0.40	0.51

[1]MM = median motor; UM = ulnar motor; MS = median sensory; US = ulnar sensory; PM = peroneal motor; SS = sural sensory. Prior to calculating changes, NCV values were adjusted for differences in skin temperature according to the method of de Jesus et al (1973).

Nine crew members had the largest magnitude change during the BL to DPE time period, all but two who were M109A3 crewmen. These changes included decreases in NCV for at least 5 out of 6 of the nerves measured and decreases in at least one nerve that was greater than 2.5 m/sec. The largest decreases observed were 11.6 and 8.0 m/sec, both for the ulnar sensory nerve, in the BL --> DPE and IPE --> DPE periods respectively (not temperature corrected). Peak blood lead for these 9 crew members ranged from 21 to 34 μg/dl.

OTHER

Hatch Status

A review of crewmen activities inside the howitzer cab and recorded on video tapes was made by the Operational Test and Evaluation Agency (OTEA). This review was supplemented by field notes made by OTEA members. Video tapes were observed for periods of time when cab hatches were open relative to periods when high zone charges were fired. A complete review of Exercise II and III tapes was made and random periods from Exercise I were evaluated. From the tapes and review notes, no special effort was made by the howitzer crews to close hatches for protection against blast overpressure. Approximately 50% of the time most of the hatches were open. Several of the hatches were open almost all of the time.

Mission-Oriented Protective Posture - Respiratory Protection

Mission-Oriented Proective Posture (MOPP) gear was worn during portions of Exercise II in order to assess crewmen ability to operate the howitzer during a simulated chemical attack. The highest degree of chemical protection occurs during MOPP 4, when the crewmen are wearing facemasks which offer respiratory protection. These facemasks will prevent inhalation of combustion products, including lead. During periods when high zone charges are fired, air sampling data will not be correlated with blood lead changes. Appendix J, Table J-1 contains data on when respiratory protection was worn, as assessed from video tapes and field notes provided by OTEA for HIP crews. Data was not available for M109A3 crews. Air sampling data for Exercise II was corrected by the procedure described in Appendix J, Table J-2, to account for lower exposures. The corrected data was used in the air to blood correlation analysis described below. M109A3 crews were assumed to be wearing respiratory protection during the same period.

Carbon Monoxide

The analytical laboratory was requested to analyze for blood carboxyhemoglobin in the same blood samples that were submitted for lead analysis. Data from these analyses are tabulated in Appendix G. Fifteen individuals achieved maximum COHb values of 15%. Fifty-three out of 77 individuals (69%) equaled or exceeded the 10% criteria contained in Military Standard 1472C (Ref 20).

CORRELATIONS

The relationship between Time Weighted Average and the Number of Rounds Fired

Analysis of variance indicated a significant difference between HIPs and M109A3s ($F=83.79$, $p<0.05$), as well as a significant difference in the number of rounds fired (Appendix H, Table H-4A). Therefore, simple regression analysis was performed for each weapons system. Analysis, by weapons system indicated a significant relationship between rounds fired and TWA, not considering field exercise, for the M109A3s but not for the HIPs. However, there was a marginally nonsignificant exercise effect for the HIPs (Appendix H, Table H-4A). Analysis by weapons system, by field exercise showed a significant relationship and a high correlation coefficient between rounds fired and TWA for HIPs for field exercises I and III, and for M109A3s for exercises II and III (Appendix H,

Table H-4B). Figures 14 and 15 show the regression lines and equations for those weapons system/exercise correlations that were significantly related.

Data Analysis for Relationship Between Air Lead Concentration (Mean 8-Hr TWA) and the Change in Blood Lead Levels and Between Air Lead Concentration and the Maximum Blood Lead Level

Maximum (Peak) blood lead level and ΔPbB were examined for a relationship with mean 8-hr TWA. Cumulative air lead exposure was considered, but not performed because air concentration data for the pilot period was not available; the period over which maximum PbB increase occurred.

Relationship Between Mean 8-Hr TWA and Change in Blood Lead Levels

There was a significant weapons system effect (a significant difference between HIPs and M109A3s) for the relationship between mean 8-hr TWA and ΔPbB. There was a significant field exercise effect (a significant difference(s) among the three field exercises) for the relationship betwen mean 8-hr TWA and ΔPbB for HIPs. Analysis for M109A3s showed no overall exercise effect. There was not a significant relationship between the mean 8-hr TWA and the change in blood lead levels for either HIPs or A3s when examined by weapons system by exercise. (Appendix H, Tables H-5A and H-5B).

Relationship Between Mean 8-Hr TWA and Maximum Blood Lead Levels

There was a significant effect of weapons system and maximum blood lead levels in the relationship between MaxPbB and mean 8-hr TWA, but further analysis showed that it was contained in the M109A3's in field exercises II and III. Therefore, further analyses were done by each weapons system. Analysis for HIPs and M109A3s showed a good fit to the model. However when examined by exercise, there was no significant relationship for HIPs between maximum blood lead levels and the mean 8-hr TWA (Appendix H, Tables H-6A and H-6C). Figure 16 illustrates the regression lines fitted to the data and related regression equations for M109A3 exercises II and III.

Data Analysis for the Relationship Between Blood Lead and Free Erythrocyte Protoporphyrin, Hemoglobin, and Hematocrit

The log FEP was tested for a relationship with PbB. FEP is expected to increase as PbB increases, especially for measurements made after 120 days of exposure and a PbB of >20 μg/dl. The analysis examined both differences between populations and differences with the measurements made at the delayed post-exercise removed (181 days). Tests for model fit, main effects and effects by unit (HIP vs A3) are in Appendix H, Tables H-7A - H-7K. A significant correlation was found to exist between PbB and FEP in the HIP and A3 populations and both HIP subpopulations when tested for all time points.

The R^2 value for the HIP medical surveillance subpopulation indicated that the linear regression provided a reasonable fit (Appendix H, Table H-7A). The correlation remained for the HIP population when the DPE timepoint was removed from the analysis. The analysis further showed that for all time points, effects-related blood lead and the interaction of PbB with subpopulation were significant for HIPs, while time (day) effects were significant for M109A3s. When Day 181 was removed from the analysis, day effects dropped out as significant for the A3s and became significant for the HIPs.

Examination for relationships between PbB and Hb were not promising (Appendix H, Tables H8A - H8J), although examination of main effects showed that removal of day 181 provided a better correlation. A relationship

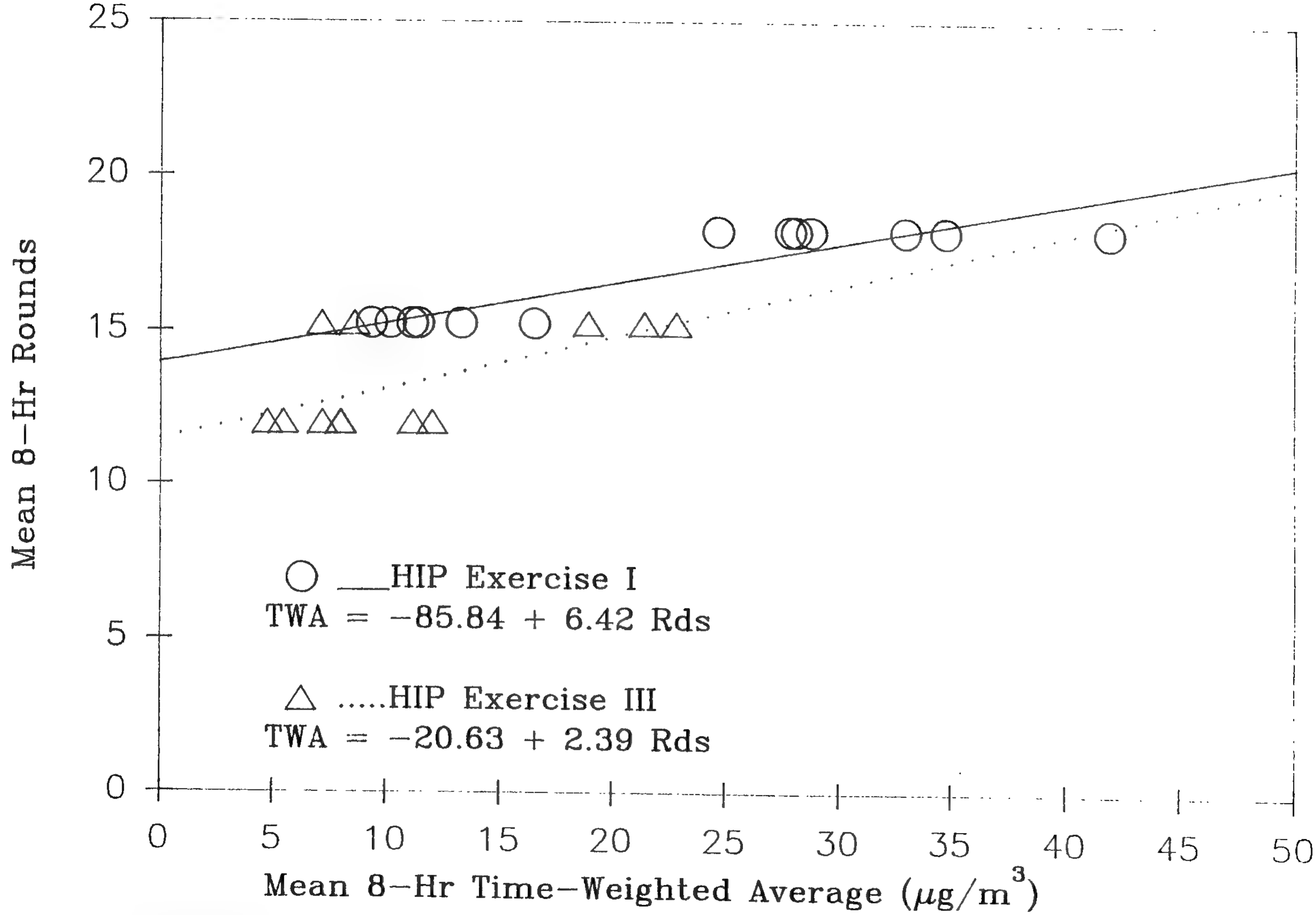

Figure 14. Correlation Between Mean 8-Hr Rounds and Mean 8-Hr Time-Weighted Average for HIP Weapons Systems

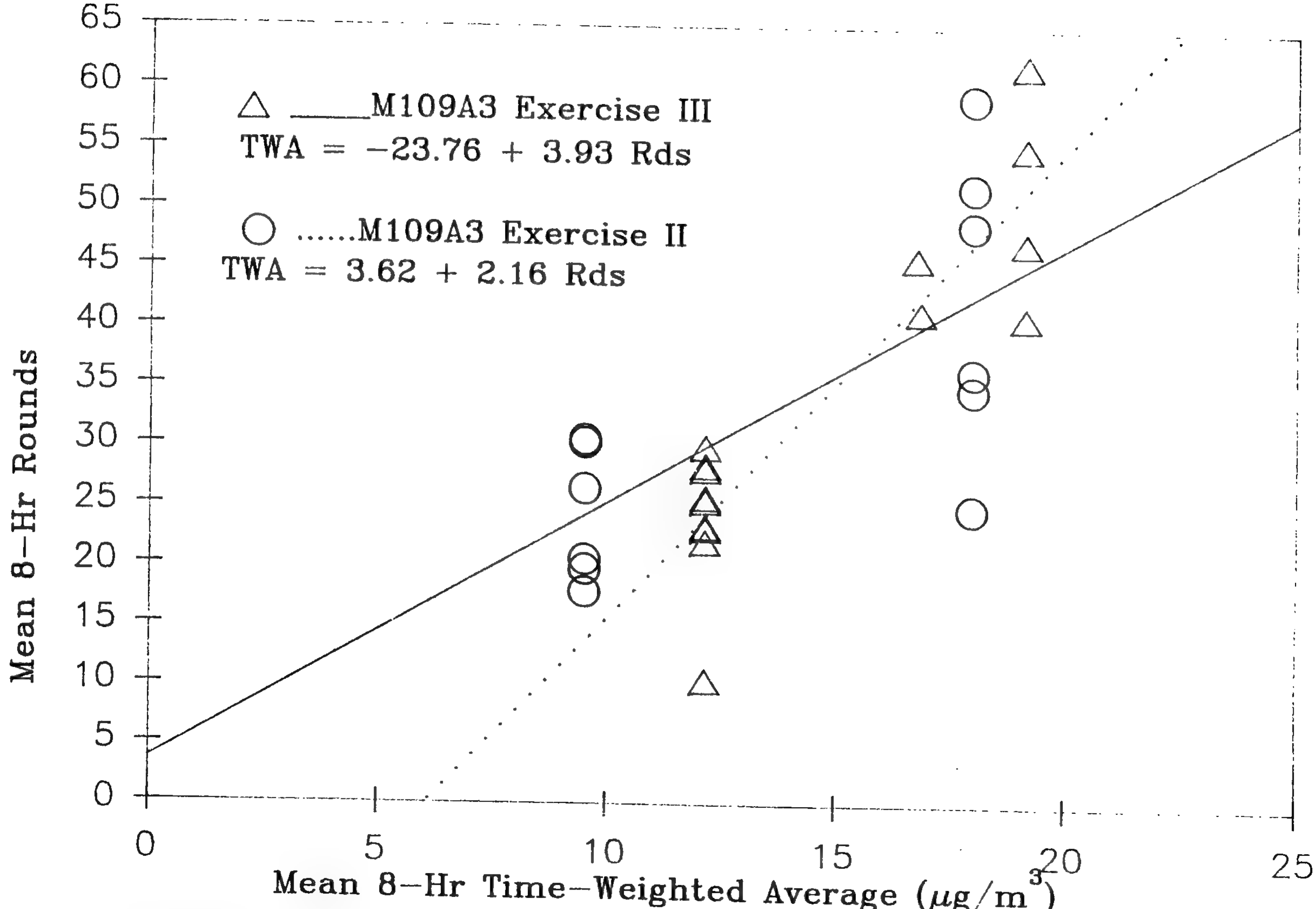

Figure 15. Correlation Between Mean 8−Hr Rounds and Mean 8−Hr Time−Weighted Average for M109A3 Weapons Systems

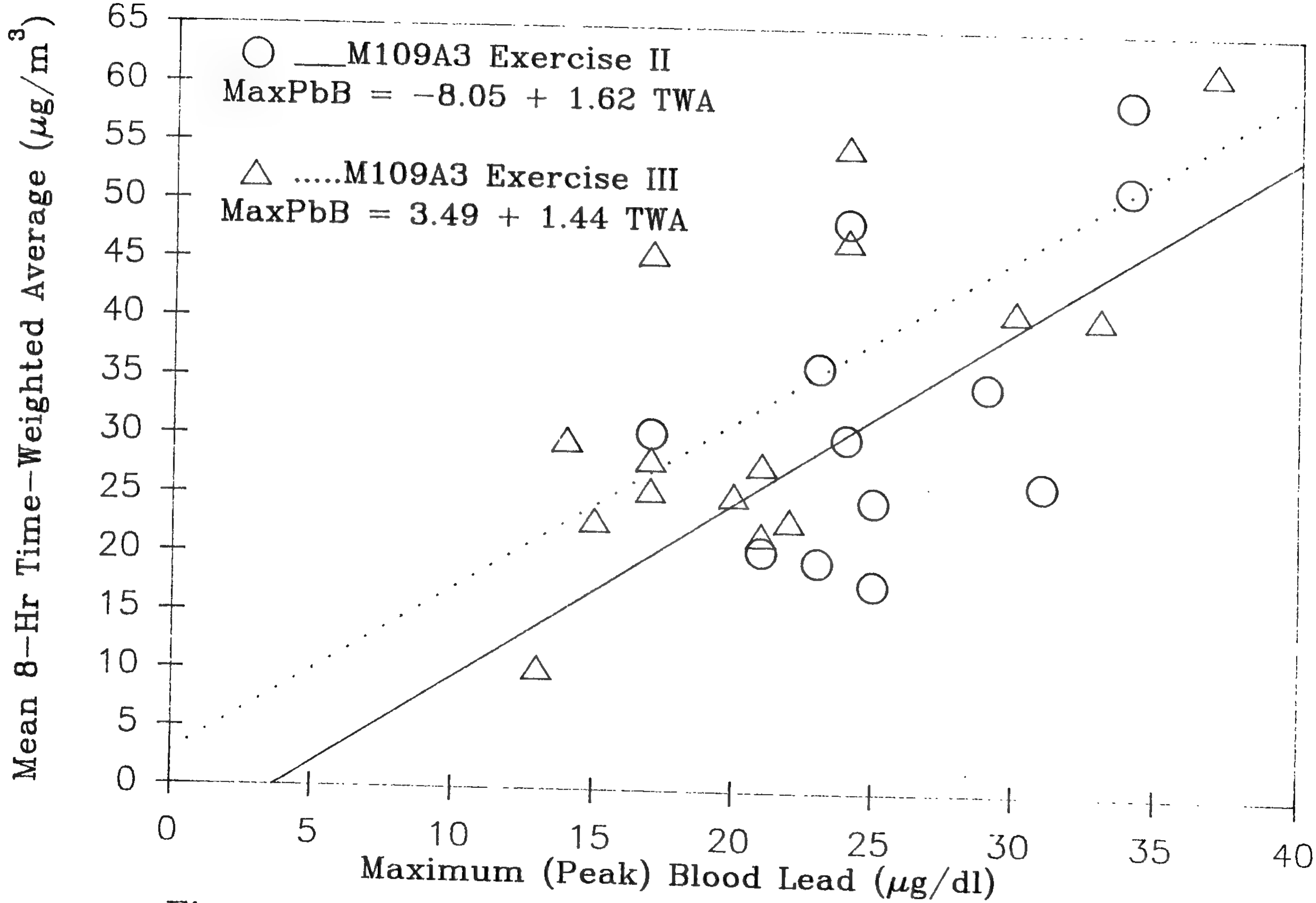

Figure 16. Correlation Between Mean 8−Hr Time−Weighted Average and Maximum (Peak) Blood Lead for M109A3s

was established between PbB and Hct for the HIP medical surveillance subpopulation (Appendix H, Tables H-9A - H-9J) after day 181 was removed from the analysis.

Correlations between Carboxyhemoglobin, Free Erythrocyte Protoporphyrin, and Hemoglobin

COHb levels were tested for relationships with FEP and Hb. As COHb increases, FEP levels have been reported to decrease. Main effects, model fit and weapons system effects are described in Appendix H, Tables H-10A - H-10L. Significant relationships existed for crewmen in both the HIP and A3 populations and for both HIP subpopulations. With day 181 removed, only the HIP population had a significant relationship between COHb and FEP. When tested by subpopulation, the relationship was present in both the HIP medical surveillance and lead study subpopulations. R^2 values for both subpopulations suggested a good fit to the linear model, which improved when day 181 was removed.

When COHb and Hb were tested, a significant relationship existed for both HIPs at the weapons system level and for the HIP lead study and the A3 medical surveillance subpopulations when day 181 was removed (Appendix H, Tables H-11A - H-11H). However the R^2 terms suggested that the linear regression was not the proper model to describe the relationship. Significant day effects were present when the DPE time point was dropped out of the analysis.

Correlation between Change in Blood Lead, Maximum Blood Lead, and Blood Lead Increase from True Initial Baseline and Nerve Conduction Velocity for Six Nerves

Analysis of variance indicated that the only significant difference between HIPs and A3s for ΔPbB, maximum PbB or increase from true initial baseline was for the relationship between ΔPbB and the ulnar motor nerve (UM) over the time period baseline to IPE. The data were pooled for further analysis (Appendix H, Table H-12A). After pooling there were no significant effects of ΔPbB on any of the six nerves. A significant effect of maximum blood lead on the median sensory nerve (MS) was found for the time period BL to DPE, however the correlation coefficient proved to be poor. A significant effect of the rise in blood lead from true initial base line on the UM for the period BL to DPE, again however the correlation coefficient was weak (Appendix H, Table H-12B).

DISCUSSION

AIR EXPOSURE

Principal Determinants of Exposure

Early in the planning stages of this study, it was recognized that several components of the air sampling system would be vulnerable to the rugged physical environment associated with howitzers and their crews. The sampling equipment, designed for industrial hygiene studies in, for the most part stable surroundings, would be subjected to blast overpressure, large particulate loads and considerable, albeit unintentional, abuse as the crewmen carrying the equipment performed their duties in confined spaces. Although only two pumps were destroyed, it did become necessary to estimate several airborne lead concentrations due to malfunctions which resulted in premature stoppage of the pump. There were also problems in obtaining adequate data for the number of rounds fired and for meteorology during the periods of intense firing. There was also some evidence that as the number of rounds increased in a period the per round concentration-time product dropped, i.e. filter clogging was occurring. Despite these difficulties, this study was able to establish evidence that PbA correlates with the number of rounds fired for 4 out of 6 exercise periods. When 2 sections in the same weapons systems had significant differences in exposure, 4 out of 6 comparisons had higher round totals associated with higher exposures.

For the most part head winds, which have been identified as the cause of elevated exposures in previous howitzer studies, did not occur very often during the HIP IOTE. Qualitative assessments that head winds or quartering winds were responsible for differences in concentration levels were only marginally convincing for A3s and not at all for HIPs.

Air lead concentrations for most of the 8 and 24 hr periods were substantially higher than exposures in the British 105mm, the 8-in and the HELP M109 studies. Seven individuals had 24-hr Ct values in excess of the worst case situation predicted for the IOTE by the US Environmental Hygiene Agency, based upon development test data collected at Yuma Proving Ground. Despite the filter installed on the HIP howitzer and the dispersion associated with the FAASV crew's distance from the howitzer, almost all of the test subjects regularly exceeded the OSHA PEL. These exposures may have actually been higher if filter clogging occurred and may have been potentially higher if head winds had been more prevalent.

Gunners were at greater exposure risk as compared to FAASV crewmen in two exercises for HIP crewmen and in one exercise for A3 crewmen (an additional exercise was marginally non-significant). The double exposure resulting from the breech emission and the muzzle emission, plus the confined space appear to insure that a significant exposure will occur for gun crews. FAASV crewmen exposure meanwhile is more susceptible to the vagaries of wind speed and direction.

It was difficult to determine if the filter on the HIP cab made a significant difference in exposure, as compared with the A3. Direct comparisons in combined gun and FAASV exposures between the HIP and the A3 demonstrated that the HIP weapons system crewmen had lower exposures despite higher round totals in Exercises I and II. Also in Appendix K, Tables K-1 and K-3 which are based upon most of the available data for the HIP, there is no clear pattern supporting the significance of the filter. With the hatches open most of the time for the HIP weapons during the IOTE, and with the added breech emission, the role of the ventilation system filter would seem at best to be minimal.

The best data on the amount of exposure on a per round basis is illustrated in the Appendix K data for number of rounds fired less than 10. The data for M119 in Table K-1 and for M203 in Table K-3 appear to be fairly consistent except for the development test data taken at Yuma Proving Ground. The data should also be fairly reliable since firing less than approximately 10 rounds in a sampling period should produce less material to clog filters and a shorter time period for other variables associated with the weapons system and the meteorology to change. On the basis of this argument, a case can be made that exceeding the PEL is possible with as few as 3 - 5 rounds. From the standpoint of administering an OSHA compliance program, requiring respiratory protection and blood samples when 3 - 5 rounds are fired would probably be more difficult than establishing the requirement when any high zone rounds are fired. Low zone rounds, on the other hand, appear to be free of any significant lead hazard, not only as noted in this study but also in studies by Bhattacharyya (Ref 2) and Menzies (Ref 21) which document that firing charges without lead foil will not produce adverse lead exposures.

The Relationship Between Aerosol Characteristics and Blood Lead Response

The mean baseline blood lead value of 4.6 μg/dl for the entire group is quite low. Even though individual values for some of the soldiers suggested a prior exposure, the mean value is below that of a non-occupationally exposed male population age 18 - 74 reported from a survey of the U.S. Population (16.9 $\pm$0.29 μg/dl)(Ref 22). Creason et al (Ref 23) reported from a survey in 1976 of 1690 male military recruits a mean PbB of 35.0 μg/dl, the principal source of which he attributed to place of residence and race (significance at the 0.01 level). The low values exist in this study despite FEP evidence of prior exposure, at least in the M109A3 population, and provide limited evidence of no lead storage in hard tissue.

Bhattacharyya et al (Ref 2) conducted aerosol characterization on M109A3 and HIP weapons (discussed previously in the introduction). Size fractions of aerosol collections from impactors are described in Table 18.

TABLE 18

HIP Particulate Size Fraction Distribution[1]

Size Fraction (µm)	>10	3 - 10	1 - 3	0.3 - 1	<0.3
% of Total Mass	2	9.5	1.5	3	83.5

[1] Mean of 2 samples taken from inside the HIP cab; Taken from Ref 2.

Although the distribution is bimodal, clearly the largest quantity is in the size fraction < 0.3 µm. The total of the aerosol mass < 1 µm is 88%. All inspired particles < 1 µm are generally assumed to deposit in the gas exchange region and be absorbed with 100% efficiency. The Bhattacharrya study also determined from scanning electron microscopy/X-ray diffraction of samples taken from inside the cab of an M109A3 that high zone charges produced a "lawn" of small spherical particles 0.5 - 5.0 µm. These particles were determined to be high in lead content. It is likely because of the shape and size of these particulates that the majority of lead in the combustion aerosol was the result of recondensed lead fumes. A further study dissolved weapons aerosol lead from an 8-in howitzer in an acetate buffer adjusted to pH 4.8 in order to reproduce the pH of macrophage liposomes. The aerosol lead dissolved at the same rate as lead nitrate and lead carbonate. By 4 hours, 50 - 60% of the lead had dissolved.

Bhattacharyya (Ref 2) also reported on the % lead per total sample weight for the A3 and HIP weapons, inside the cab and at various outside locations. Table 19 displays these data.

TABLE 19

Mean Percent Lead by Weight of Sample[1]

Weapon System		Zone 8 (M203)		Mixed Zone 7 + 8 (M119 + M203)	
		Inside[2]	Outside[3]	Inside	Outside
M109A3					
	Mean	3.3	15.7	5.0	9.9
	SD	0.8	7.1	0.8	5.1
HIP					
	Mean	7.6	14.3	-	-
	SD	3.3	6.7	-	-

[1] Taken from Ref 2
[2] Inside refers to samples taken in the howitzer cab, resulting in predominantly exposure to breech emissions
[3] Outside refers to samples taken at various locations around the outside of the howitzer, resulting in predominantly exposure to muzzle emissions.

The information on % lead per total sample weight leads to the conclusion that almost all of the aerosol lead exposure would be available for respiratory deposition and absorption (assuming that the outside particulate distribution is similar to the particulate distribution inside the cab) and that exposure to the muzzle emission would result in the greatest lead aerosol exposure. The M109A3 gun crew, without the cab filter, should receive the

highest overall exposure to both the muzzle and breech emissions. The lead aerosol distribution may have contributed to A3 crews overall receiving from 1.5 to 3 times greater lead exposure and A3 gun crews in particular receiving 1.6 to 2.7 times greater lead exposure. Despite having lower mean PbB at baseline, the greater exposure resulted in a more pronounced rate of PbB increase for the A3 crews, such that PbB at IPE had become essentially the same as the HIP crew.

Hodgkins et al. (Ref 24) noted that attempts to correlate PbA with PbB often fail because the fraction of lead exposure that is inhalable is not considered. The failure to consider particle size often leads to model predictions, including the one adopted by OSHA for the lead standard, to underpredict the degree of absorption from aerosols with a high content of particulates < 1 μm. When mean 8-hr time-weighted average was tested in this study with change in blood lead, the relationship proved to be statistically significant, however exercise effects precluded identifying which aspect of the exposure was responsible for the relationship. Further analysis of mean 8-hr TWA with maximum (peak) PbB proved to be more successful. A significant association was found in two A3 exercises with resultant R^2 of 0.37 and 0.53 as evidence of good fit to a linear regression model. The R^2 value of 0.53 is comparable to R^2 values cited by Hodgkins et al (Ref 24) for various successful model fits based upon consideration of respirable particulate mass. The high correlation for the second and third exercise can probably be attributed in part to the high percentage of respirable lead aerosol in weapons emissions. As stated in the introductory section, small arms firing range aerosols have particulate size distributions with higher percentages above 1 μm that howitzer aerosols. Valway et al (Ref 25), however in a study of lead absorption in firing ranges did find a significant correlation when cumulative exposure and change in PbB were assessed.

Argonne National Laboratory (Ref 2) found a significant relationship between cumulative PbA and cumulative PbB over the period BL --> DPE which had a high correlation coefficient ($R^2 = 0.85$, $F = 142$, $p = 0.0001$). The slope of the regression line for the period of highest exposure was about tenfold less than values obtained for human exposed experimentally or environmentally to 1 - 10 μg/m^3 of lead oxide. Any further analysis of the howitzer data from this study should consider the use of cumulative exposure based upon exposure estimates for the pilot period.

Blood lead reached a peak after exercise II and declined from this point to IPE, despite continued exposure during exercise III. Bhattacharyya (Ref 2) also obtained a similar response during the last week of a three week firing exercise. Several authors have noted that PbB reaches a plateau, depending on the duration and concentration of the exposure, while the heavy metal load continues to increase in the body (Ref 26, 27, 28 and 29). The initial blood lead increase prior to the plateau is often the fastest increase observed during the period of exposure (Ref 26 and 30) and was also observed in this study. Grobler et al (Ref 31) explored the plateau phenomenon in a study on rats. For exposure concentrations equivalent to those in Griffin (Ref 26), initial increases and plateau levels of PbB in rats proved to be approximately the same. Grobler et al found that the higher the exposure, the sooner a stable blood burden was reached. Grobler et al also noted that faster declines in PbB after exposure occur for the lower exposed groups (77 and 249 μg/m^3 for 77 and 28 days respectively, as contrasted with the higher exposed group at 1546 μg/m^3 for 50 days) which may be the result of insignificant amounts of metal being stored in hard tissue. One author (Ref 32) has speculated (apparently, because no data was cited) that brief intense exposures result in maximal excretion through urine and feces, with minimal deposition in bone. Without concurrent urine and fecal lead measurements however, this suggested phenomenon could not be explored in this study. Experiments in humans by Kehoe (Ref 33) included daily chamber exposures of 20 μg/m^3, supplemented by 150 μg/m^3 to simulate occupational exposure. The supplementary exposure was for varying periods between 3 hr every other day to 13 hr/day, 6 days/week. These subjects never exceeded a PbB higher than 40 μg/g (usually 20 μg/g) and never reached PbB equilibrium. Almost all of the dietary and inhaled lead was seen in the urine and feces.

Blood Lead, Free Erythrocyte Protoporphyrin, Hemoglobin and Hematocrit Responses with Time and Between Weapons Systems

Initially, the choice of a variable to represent lead injury to protoporphyrin metabolism in blood samples (collection of urine samples was not considered logistically feasible) was difficult to identify. Many references cited the necessity to obtain FEP, EP or ZPP measurements when these values and the PbB became stable or

steady-state (Refs 27, 30, 34 and 35). These recommendations occurred primarily because statistical significance and valid correlations were not obtained in newly exposed workers until approximately four months to one year after initial exposure. These observations may have also been influenced by the investigators having principal experience with industrial exposure situations that were also relatively steady-state. We knew before the study that artillerymen would be exposed to episodic, intermittent PbA. One of the authors reviewed (Ref 36) did obtain good correlations between PbB and ZPP in one of two groups with the shorter exposure period (4 - 96 months versus 21 - 131 months). He commented that the relationship should not be influenced by short term variations in exposure to lead due to an averaging effect.

Several authors have reported FEP to be superior to ZPP (Refs 37 and 38). Harada and Miura (Ref 37) in particular noted that FEP may be superior in the acute stage of lead poisoning because FEP represents total erythrocyte protoporphyrin and because ZPP was considered to be a secondary product in protoporphyrin metabolism. Based upon this information, FEP was chosen as a measurement parameter for this study. Other reports have noted inconsistent correlations between PbB and both ZPP and FEP in changing exposure conditions (Ref 39). For practical purposes however, FEP is equal to ZPP when iron deficiency is excluded and FEP is less than 100 µg/dl (Refs 37, 38, 39, 40 and 41). We have assumed that iron deficiency is not a problem in this population.

Differences existed at baseline between HIP and M109A3 crewmen blood values for PbB, FEP and Hct. HIP crewmen had elevated PbB and Hct, while M109A3 crewmen values for FEP were higher. Both crews may have had recent exposure, but the HIP exposure appears to have been more recent.

The in depth analysis of blood lead changes with time since the start of pilot training indicate that the major increases occured in the first period after the start of pilot training and before the initiation of the formal IOTE (PRE1). Blood lead increases of 11.2 µg/dl for HIP and 10.6 µg/dl during the pilot period were the largest increases of the study.

In the six point time analysis for the Lead Study population, despite apparently different exposure histories, rates of change between the two weapons systems in the pilot period showed a constant PbB/time relationship.

Exposure during the initial exercise period (PRE1 --> POST1) produced a PbB increase that was significant for the A3s, but not the HIPs. The smallest exposure difference between the two weapon systems also occurred during PRE1 --> POST1. Blood lead increases for the other time periods were equivalent, despite differences in exposure. When PbB increases over BL --> IPE are analyzed for the medical surveillance population (3 time points) there were significant differences in rates of PbB increase between the two weapons systems and A3s had the higher rate of increase, further supporting the observation of higher exposure for these crewmen.

There was no difference in PbB values decreasing between the two weapons systems over the time period IPE --> DPE, suggesting that blood elimination kinetics were similar. Final PbB values represent $t_{1/2}$ values from the time period of last exposure of approximately 60 days. Although this figure is twice the 30 days normally cited for blood elimination in humans, Kang and Infante (Ref 42) have documented that as the baseline is approached, PbB values fall more slowly (expotentially).

FEP decrease for the M109A3 crews from baseline to the PRE1 sample are difficult to explain given the heavy firing activity during the initial pilot test 14 April - 22 May. Increases in FEP are normally seen 21 days after PbB begins to rise. Slight increases in the HIP population BL to PRE1 were expected; and further increases POST1 to IPE follow the expected lag pattern. Some factor associated with the intermittent exposure may have been responsible for the A3 FEP decrease during BL to PRE1. These declines were especially prominent in the 7 individuals with the highest air lead exposure and the highest peak blood lead (all M109A3 crewmen). Lerner et al (Ref 39) expressed the opinion that the decline in FEP following a return to exposure during the period when PbB is rising may be explained by the introduction of new red blood cells with low FEP from the marrow into the pheripheral blood. FEP values were quite similar between populations at IPE, despite the headstart for the M109A3 population; however HIP rates of increase IPE --> DPE were higher. M109A3 crewmen FEP values remained higher than HIP crewmen values at DPE.

Overall the number of individuals with FEP elevations above 35 µg/dl were small and the relative elevation is not similar to those values seen in a wide variety of chronic industrial lead exposure situations (The highest FEP value recorded was 51 µg/dl).

Despite statements in the literature that log FEP and PbB correlations could not be found or were poor in other than steady state exposure conditions, a correlation was found in the HIP population which remained when the six weeks post measurement was excluded. The correlation with the HIP medical surveillance population was especially strong ($r = 0.70$) with the intermediate measurements not a part of the analysis. Significant time effects were prominent in the A3 analysis which appeared to preclude a correlation for this population. The regression equation is fairly close to those in a list published by Wildt (Ref 43) and Kracic (Ref 40), with similar r values (Table 20). Labreche and P'an (Ref 27) published correlations for groups at different exposure levels, none of which individually produced a strong correlation, but when combined groups were evaluated, the correlation was especially strong. In the Labreche and P'an study, at least, duration of exposure did not lead to a strong relationship. The overall relationship had approximately the same slope, but a higher y-intercept than the other published studies.

TABLE 20

Regression Equations for the Relationship Between Free Erythrocyte Protoporphyrin and Blood Lead

Equation	Correlation Coefficient (r)	Blood Lead Range (μg/dl)	Reference
Log FEP = 1.197 + 0.0123PbB	0.70		This study
ΔFEP = 0.294PbB - 0.02	0.37	5 - 17	Ref 2
Log FEP = 1.12 + 0.0106PbB	NA	18 - 43	Ref 41
Log FEP = 0.95 + 0.0190PbB	NA	14 - 60	
Log FEP = 1.06+ 0.0135PbB	NA	12 - 60	
Log FEP = 0.94+ 0.0117PbB	0.51	10 - 90	
Log FEP = 0.86+ 0.0169PbB	NA	20 - 80	
Log FEP = 1.354 + 0.017PbB	0.72	NA	Ref 38
Log FEP=2.37+.0174PbB	0.91	18.7 ± 6.1	Ref 25

The FEP values reported in this study may have been artificially low. carboxyhemoglobin levels of 20% have been shown to result in a decrease of 14% in ZPP readings (Ref 27). The interference results from the influence of carboxyhemoglobin concentrations on hematoflourescence ZPP readings. National Health Laboratories did not correct for COHb interference. The relationship between COHb and FEP was investigated. A highly significant relationship was found in the HIP population which demonstrated that as FEP increased, COHb also increased ($r = 0.61$). Since our expectation was that FEP should decrease as COHb increased, the observed relationship suggests that interference may not have been a problem.

These data are not accurate reflections of peak COHb. First, sampling protocols were not designed to measure baseline and immediate post-exposure COHb levels in order to properly characterize COHb blood dynamics. Post-exercise blood samples were approximately two to three hours after the last firing period. The average $t_{1/2}$ for COHb elimination from the body is four hours, which would suggest that peak levels would have been as high as 25 - 30%, if an assumption is made that peak levels were achieved during the last firing period. Second, the procedure used for COHb analysis is not the procedure of choice for blood COHb. Improved accuracy

can be obtained by using CO-oximeters which have measurement accuracy of ± 1% for values greater than 5% COHb. Further accuracy and resolution below 5% can be obtained using gas chromatographic techniques. A review of the data shows most of the values clustered around 5% COHb increments. Following a discussion with the analytical laboratory, and a review of the calibration curve, it would appear that the procedure is not precise enough to identify COHb values of 1%.

Despite the apparently mild PbB changes, hematocrit values below 42% and Hb values below 14 g/dl occured in 29% of both HIP and A3 crews, especially during the middle of the IOTE period (POST1 and POST2). Recovery was evident by IPE. Several authors have stated that both Hb and Hct are insensitive to PbB increases (Ref 34) or that Hb decline would not reach levels of lead based anemia (< 14 g/dl) unless PbB increased substantially (60 µg/dl - Ref 36; 104 µg/dl - Ref 44). Hryhorczuk et al (Ref 45) observed very high ZPP levels in a chronically exposed population, but only 30% had Hb levels < 14 g/dl. Because the blood samples in the study were taken fairly close together in time and did show recovery, even during periods of continued exposure, these changes probably represent physiological adjustment in the production of red blood cells. A statistically significant correlation between increasing PbB and decreasing hematocrit is further evidence for these changes, especially in the HIP population. The r value of the correlation was not very high however and was based on only two data points. Some authors have found statistically significant relationships between ZPP and Hb (Ref 43) or improved relationships between ZPP and PbB when Hb was incorporated into the analysis (Ref 41).

We investigated the potential role of COHb on Hb values. Our hypothesis that Hb should increase as COHb increased proved to be statistically significant for BL to IPE for both populations. Values of r however, were not high. This relationship probably exists because of the rebound of Hb values at IPE, an effect more likely due to increased hematopoeisis caused by the lead challenge, rather than the COHb effects; or perhaps due to a synergistic effect of the two insults.

Correlation of blood parameters should be interpreted with consideration of the following characteristics of the studied populations. First, despite larger overall PbB, FEP and Hct changes for the A3 crews, significant correlations almost exclusively appeared in the HIP population. The apparent reason for this discrepancy lies in the significant exposure differences of A3 sections, as compared to HIP sections (see Appendix H, Tables H2A, H2E and H3C for section effects). Second, the failure of linear regression models to adequately describe the lead study population (6 time points) is not unexpected, given that the blood parameters were responding rather rapidly to changes in the intermittent exposure. Removal of the data point for the post exposure period did improve most of the correlations. A better fit for the PRE1 --> IPE period may be possible using a curvilinear model. Third, significant correlations involving the medical surveillance populations should be viewed with some caution, since only 3 data points are used in the analysis (only 2 data points when DPE is removed). Actually in one sense, the improved correlations for the medical surveillance population are probably more consistent with the literature than the lead study population because the time period between blood samples has been extended.

Blood lead mean values were comparable to the British 105mm howitzer, but above the HELP M109A3 study mean of 16.19 ±6.23 µg/dl and the ANL 8-in battery means of 8 and 11 µg/dl. The maximum PbB in the ANL study was 17 µg/dl (Ref 2). Blood lead values at DPE did not fall significantly after IPE and were still 5.4 µg/dl above baseline at 6 weeks post-exposure. Small but significant changes in FEP and Hct were observed over the period BL --> IPE for the highest exposed group. Statistically significant correlations were obtained for PbB with FEP and Hct, but the correlation coefficient was strong only for the period of decrease from IPE to DPE (Ref 2).

Overall the absolute values of the various blood parameters are quite low as compared with workers chronically exposed to lead. The observed changes over the time period of the IOTE appear however to be much more sensitive to exposure than suggested by previous work.

Nerve Conduction Velocity Responses

By using each subject as his own control, we were able to obtain a sensitive measure of NCV changes. None of the other studies of NCV changes due to occupational exposure have reported use of the subject as his own control except for a companion study supported by USABRDL (Ref 2). Measurement error was also less than reported for other studies. We obtained a measurement error of less than 2%, which should make the measurement

quite sensitive to any changes. Even though we were unable to obtain a baseline prior to the pilot test period, most of the other studies involving occupational exposure have had initial measurements made at some period after exposure. Most studies report that arm nerves (Median Motor [MM], Median Sensory [MS], Ulnar Motor [UM], Ulnar Sensory [US]) and sensory nerves are initially affected; with the median nerve being affected more frequently than the ulnar (Refs 46 and 47). One study reported the threshold for effects in children at 20 µg/dl (Ref 48), but most have reported effects for adults occupationally exposed starting at 40 µg/dl. Other studies of relevancy to the transient, intermittent type of exposure have reported that NCV decreases are greatest when exposure to PbB is low (Ref 49) and during the postexposure period when NCV increases are large (Ref 15).

Although individual temperature differences in our study were never more than $1^{o}C$, temperature corrected data were often improvements over the non-corrected measurement. For BL to IPE the correction proved significant for the US and PM, while the SS changed from significant to nonsignificant. BL to DPE temperature corrections essentially did not change the statistical significance of the PM or the SS. Changes IPE to DPE were significant only for the UM and SS (marginally non-significant for US)(not temperature corrected)(marginally non-significant change for MS BL to DPE). All of the changes for NCV were negative, except for the US (temperature corrected) during BL to IPE, which was an increase.

Antagonistic effects of blood copper and blood lead on NCVs have been reported by Murata et al (Ref 50). Air copper (fume) concentrations ranging from roughly one-half to slightly above the American Conference on Governmental Industrial Hygienists Threshold Limit Values were reported for the HIP howitzer by Bhattacharrya et al (Ref 2) and in this study (Ref 51).

Despite the somewhat erratic nature of these results, the changes for the PM and the SS, and perhaps the US appeared to be real. Seppaleinen (Ref 47) evaluated initial NCV changes (1 - 6 weeks after the commencement of exposure) at 1 year in a cohort of battery workers. One set of comparisons was made between exposed and controls and a second set of comparisons was made between those with median PbB less than 30 µg/dl and those greater than 30 µg/dl. At one year statistically significant changes were seen for the NCV of the median motor and the median sensory in the comparison between exposed and controls. At one year differences between the high and low exposure groups were seen in the median motor and sensory and the ulnar motor and sensory. The peroneal motor NCV had decreased at 1 year ($p = 0.051$). No changes were noted in the sural sensory nerve.

Muijser et al (Ref 15) examined NCV changes in eight men intermittently exposed during the burning of lead-based paint over a 5-month period. Measurements were made on the median and ulnar motor and sensory nerves. Initial NCV measurement was made after the termination of exposure and at 3 and 15 months post exposure. Exposed subjects were compared with an unexposed control group. Statistically significant changes were not found at the termination of exposure or at 3 months post exposure. Statistically significant increases in the median and ulnar motor nerves were seen at 15 months. These changes were interpreted by the authors as a return to normal following decreases during the exposure period. Feldman et al (Ref 52) also investigated workers exposed to lead as a result of burning paint, and found a large decrease of 5.8 m/s in the peroneal motor nerve (period after exposure not stated). Our largest decrease was 11.6 m/sec, found in the sural sensory nerve for the period BL to DPE.

Schwartz et al (Ref 48) examined differences between two groups of children, one an unexposed rural population with PbB < 40 µg/dl and the other a population which lived near a lead smelter and all had PbB > 40 µg/dl. Several factors were examined for a relationship with changes in the peroneal motor nerve, including PbB, area of residence, duration of residence, FEP, age, sex, and pica. Only PbB was found to be significantly related to NCV changes. Three dose response curves were evaluated for the relationship between PbB and NCV. Thresholds at 30, 20 and 25 - 30 µg/dl were found for the "hockey stick", logistic and quadratic regressions, with the logistic model being the most robust.

Bhattacharyya et al (Ref 2) found a statistically significant decrease in NCV for the peroneal motor nerve from IPE to DPE in members of the highest exposed 8-in artillery battery, and a marginally non-significant relationship in the same period for a decrease in NCV for the same nerve with ΔPbB. After changes in NCV values due to temperature corrections were made, the significance of the observed changes were considered questionable.

From the literature cited, early changes appear to be the most obvious in the median motor and sensory nerves, and the peroneal motor and sensory nerves. Our results were somewhat different than this especially for

involvement of the median nerves. We were able to demonstrate significant relationships between PbB and NCV change, but the linear model proved to be an unsatisfactory measure of correlation. Perhaps reanalysis with the models used by Schwartz would prove to be more useful.

Effects

The possibility of long term damage due to FEP and NCV changes observed in this study are the subject of some debate. Even though blood and nerve parameters were trending towards normal (baseline) values at IPE, the report of effects below the thresholds contained in the OSHA law are being noted in the literature at increasingly lower levels. None of our subjects showed classical lead poisoning symptoms, although fatigue, loss of sleep and other physiological changes due to the grueling pace of the IOTE may have masked some of these symptoms. Symptomology however is usually noted at PbB values above 40 μg/dl (Ref 53).

The FEP and NCV changes that were measured in this study are considered truly harmful outcomes and not merely homeostatic or physiological adjustments to the presence of lead (Ref 54). In fact some authors have noted mental disturbances in children as early as the initial FEP rise and others have stated that heme precursors are themselves toxic (Ref 55). In a group of subjects with a median PbB of 39 μg/dl, blood loss lead to a delayed blood regeneration (Ref 56). These subjects had otherwise normal hematological parameters prior to the blood loss. Such a decrease in the "reserve capacity" of the body has unique significance for combat conditions.

The functional correlates of NCV decreases are reduced ability to perform rapid, highly coördinated movements and prolonged reaction time (Ref 48). NCV changes have been accompanied by Electromyography readings which demonstrate partial denervation (Ref 57).

Most evidence points to CNS damage and resulting behavioural changes prior to peripheral nervous system abnormalities (Ref 58). Behavioural changes (psychomotor and cognitive) due to lead exposure have been seen in individuals with an average blood lead concentration of 30.5 $\pm$9.6 μg/dl (Ref 59).

Reproductive difficulties associated with PbB of 30 μg/dl have been reported and are identified in the OSHA standard. A companion study by this laboratory in artillerymen found tentative evidence of fertility problems (lower sperm counts/ejaculate and lower sperm/ml)(Ref 60).

Requirements for a Military-unique Lead Standard

The issue of a military-unique lead standard has been discussed for some time in the Army medical and weapons development communities. This concept is based primarily on the philosophy that short-term, intermittent exposure is not capable of causing disease. Several studies including this one, have shown that relatively small amounts of weapons firing activies will lead to violation of the air lead standard, but all of these studies have shown that blood lead has never exceeded the blood lead standard. The military-unique standard concept is also driven by the fact that compliance will probably require respiratory protection and blood lead monitoring when high zone rounds are fired, which are requirements that are not currently enforced during artillery training.

Three requirements appear absolutely essential in terms of data development before even considering a petition to the Occupational Safety and Health Administration. First, background body burdens of lead must demonstrate that short-term and career exposures have not resulted in lead accumulation. Sufficient data on blood lead levels has been developed for artillerymen to demonstrate that during non-exposed periods, PbB levels do not reflect release from hard tissue. Actual data on bone lead levels in artillerymen is inadequate. Bhattacharyya (Ref 61) initiated such a study for crewmen of different career exposure periods, however the study was canceled when Operation DESERT STORM began.

A second requirement is to demonstrate that no adverse affects occur as a result of exposure to weapons lead. This study is the first one to demonstrate conclusively that NCV changes can occur as a result of weapons aerosol exposure. What is not known from the general literature is how reversible the phenomenon is. The shortest term test, and the most militarily relevant, is to evaluate functional deficits during or shortly after periods of intense high zone firing. Weyandt's (Ref 60) preliminary study of reproductive function in artillerymen was also

terminated prematurely by Operation DESERT STORM, and was apparently confounded by subject bias. This study definitely needs to be repeated. Other long term and more difficult studies could involve examination of renal and peripheral nerve disease in artillery veterans.

A third requirement would be to demonstrate that short-term, high-level exposure results in a high percentage of the lead being rapidly eliminated from the body. These physiological dynamics have been alluded to before, but have not been proven adequately in an experimental setting. Urine and fecal measurements in a future weapons aerosol lead study would provide much useful information.

CONCLUSIONS

AIR EXPOSURE

- All but four study subject mean 24-hr exposures for PbA exceeded the PEL of 16.7 $\mu g/m^3$. Eighty-six percent of the subject's highest 8-hr and 100% of the highest concentration-time product exposures exceeded the PEL's of 50 $\mu g/m^3$ and 24,000 $\mu g\text{-}min/m^3$.

- The 24-hr PEL for air lead was exceeded by a six-fold margin 26% of the time during the 3 exercises.

- Significant PbA exposures are reliably associated with the firing of high-zone M119 and M203 charges. Mean exposures during the firing of low zone charges did not exceed the PEL.

- Weapons systems differences were apparent in all three exercises with M109A3 crew exposures significantly higher. A3 crews had the higher round total in the third exercise.

- Gun crews had higher exposures for HIPs in Exercises II and III and for M109A3s in all three exercises. HIP gunners had lower mean exposures than A3 gunners, suggesting that the cab filter may have been beneficial in protecting the HIP gun crew. The filter is irrelevant for HIP FAASV crew protection. The recommended practice of closing hatches when firing, especially for M203 charges was not conducted with any regularity during the IOTE.

- Statistically significant differences in PbA existed between HIP and A3 sections in two out of three exercises. The section with the higher round total had the higher exposure. Significant correlations between the mean 8-hr TWA and the mean number of rounds could be made during these same periods.

- Wind-related factors may have been important in Exercise III for HIPs and Exercise I for A3s as an explanation for section differences in exposure concentrations. This may be especially true when round totals did not support higher concentrations and winds were blowing from one section to another. The meteorology data however was insufficient to provide specific verification for variations in exposure concentrations.

- Exposure from firing as few as three to five M119 and M203 charges will equal or exceed the OSHA Permissible Exposure Limit.

- Exposure concentrations for periods when large numbers of rounds were fired may have been underestimated as a result of overloaded sample filters. The overall exposure may have also been less than worst case due to favorable wind patterns.

AIR TO BLOOD RELATIONSHIP

- Baseline PbB was quite low for all groups, despite evidence for recent prior exposure in the M109A3 population (elevated FEP). The mean baseline PbB is below U.S. population means and a survey of military

recruits. Questionnaire histories support no significant exposure due to other occupational or hobby activities.

- Blood lead increases did not exceed the OSHA action level of 40 μg/dl, which requires more frequent medical surveillance or employee notification. Twelve individuals had blood lead levels in excess of 30 μg/dl, a level in which OSHA requires employee counseling if fathering children is being considered.

- The majority of blood lead increases occured during the pilot training period for both HIP and A3 crewmen. Additional smaller, but significant increases occured during the first two exercises for both HIP and A3 crewmen.

- Although there were no differences in mean blood lead level between HIPs and A3s at the IPE time point, the rate of PbB increase from baseline to IPE was greater for the M109A3 crewmen. These rates of change were also more variable among the A3 sections. The higher rate of PbB increase is seen as a direct response to the higher exposure of the A3 crew as compared with the HIP crew.

- Statistically significant correlations could be found between maximum (peak) blood lead levels and mean 8-hr TWA overall, and for both weapons systems; but when examined by exercise, the correlations existed only for the A3s in exercises II and III. Correlation coefficients indicated that the linear model provided a strong explanation for the relationship between peak blood lead levels and mean 8-hr TWA.

- Blood lead values peaked for both populations after Exercise II and declined slightly after Exercise III, despite continued high air lead exposures.

- Blood lead achieved $t_{1/2}$ decreases between IPE and DPE (58 days) for both populations, but the six individuals with the highest PbB were lagging behind.

FREE ERYTHROCYTE PROTOPORPHYRIN, HEMOGLOBIN, HEMATOCRIT AND CARBOXYHEMOGLOBIN

- FEP was elevated for A3 crewmen at baseline, and HIP crewmen had higher PbB and Hct, but the absolute values for both populations met the clinical definition of normal.

- More M109A3 crewmen had elevated FEP than HIP crewmen. FEP increases were more consistent for the A3 population and the classical lag in FEP increase was more obvious in this population. Absolute FEP levels were essentially identical at IPE for the two populations, but remained elevated for the M109A3 population at DPE despite equivalent blood lead levels.

- FEP increased through all exposure periods (except the pilot period for M109A3 crewmen) and was decreasing during the BL to PRE1 and IPE to DPE periods. Fourteen crewmen exceeded the CDC FEP limit of 35 μg/dl during at least one exercise period.

- The slopes of FEP increase from BL to IPE and decrease from IPE to DPE were essentially identical for all sections and both populations. These changes mirrored essentially equivalent blood lead levels at IPE and DPE for both populations and despite varying rates of PbB increase found in the M109A3 population.

- Significant PbB/FEP correlations were found in both HIP subpopulations over all time points, which remained when the DPE time point was removed. When examined by subpopulation the correlation coefficient was more robust for the simpler medical surveillance population with only 3 time points.

- Although the mean Hct of 43.9% is considered clinically insignificant, 29% of the HIP and A3 lead study populations fell below 42% Hct during POST1 and POST2. Forty-two percent is a benchmark used by some authors to show exposure to lead. Recovery was evident by IPE.

- Hemoglobin values also fell below 14 μg/dl for 29% of both populations during the same period.

- Based upon indirect evidence, carbon monoxide levels in the artillery crewmen were quite high (20-30% COHb). High COHb levels may have depressed FEP readings by the analytical laboratory since analytical corrections were not made. COHb and FEP correlations did not appear to support this observation.

- Increases in COHb were found to correlate with increases in Hb; both the lead and CO challenges may have had some impact on Hb increases, but this observation is not clear.

NERVE CONDUCTION VELOCITY

- Analytical measurement conditions for NCV were optimized by using each subject as his own control. Limited analyst variation and minor skin temperature variation improved the sensitivity and specificity of the NCV measurement.

- Large NCV decreases of 8.0 and 11.6 m/sec were found in the ulnar sensory nerve for two M109A3 crewmen.

- Statistically significant NCV decreases were found for the peroneal motor nerve during BL to IPE and BL to DPE which persisted after temperature correction.

- Statistically significant NCV decreases were found for the sural sensory nerve from BL to IPE (not temperature corrected) and from BL to DPE in both the corrected and uncorrected conditions. The decrease was still significant in the IPE to DPE period.

- Other less reliable decreases were found for the ulnar sensory nerve and the ulnar motor nerves, with a suggestion of an increase in the ulnar sensory nerve from BL to IPE.

- Limited evidence suggests most of the changes were to be found in the A3 population, but differences in group means were not significant.

- Statistically significant correlations were found for the relationship between maximum (peak) PbB and the median sensory nerve and rise in PbB from true baseline and the ulnar motor nerve from BL to DPE, however the correlation coefficients were not very strong.

RECOMMENDATIONS

Operational

- Provide information to combat physicians on the lead hazards of artillery weapons. Until the lead-based ammunition stockpile is eliminated, the potential for acute lead poisoning during extended periods of firing high-zone charges in combat will exist. Blood lead and FEP/ZPP measurements under these circumstances may be warranted.

- Restrict soldier exposure during training by requiring the use of respiratory protection and medical monitoring when firing high-zone charges.

- Develop an alternate decoppering material as a substitute for lead.

- Develop alternate medical monitoring procedures for ZPP to correct for the presence of carboxyhemoglobin.

Research

- Examine artillerymen who fought in the DESERT STORM operation for residual lead effects, including PbB, FEP, NCV, and bone lead. In particular individuals who were also a part of previous BRDL studies (8-in Crew Ballistic Shelter, chronic effects and reproductive effects Studies) and this study (HIP IOTE) should be examined since baseline data exists on these individuals.

- Initiate a new cross-sectional chronic effects study of artillery-based lead exposure, incorporating the DESERT STORM/USABRDL Study cohort. The study should incorporate basic elements of the prematurely terminated Chronic Effects study, including stratification by age, and the pilot reproductive study.

- Collect data from future exposure studies to describe lead elimination. Samples of urine and fecal should be taken in order to determine the proportion of inhaled weapons lead that is eliminated by the body. Followup on at least a selected number of subjects over an extended period of time ($\geq$ 1 yr).

- Consider conducting neurobehavioral and peripheral nervous system experiments following field exposures to artillerymen. Previous neurobehavioral tests by Williamson and Teo (Ref 62) for neurobehavioural deficits due to lead exposure and Moody et al (Ref 63) for deficits in peripheral nervous system function have proven to be useful in evaluating occupational exposures to lead. Neurobehavioral testing protocols developed by Benignus (Ref 64, 65) for the Army to evaluate carbon monoxide-related deficits should be transferable to the lead exposure situation.

- Conduct future studies during extended artillery firing exercises to establish definitive data on carbon monoxide and the relationship between COHb, FEP and Hb during these exposures. Use of a less intrusive COHb measuring technique such as sampling of alveolar breath may be more practical in the field setting.

- Develop improved air lead sampling techniques in order to eliminate air sampler filter clogging problems. Suggested techniques might include more frequent sample filter replacement or size-selective collections.

- Incorporate in future studies which measure nerve conduction velocity, measurement of blood copper, in order to evaluate the potential impact of the antagonistic behavior between PbB and CuB.

REFERENCES

1. U.S. Army Medical Research and Development Command. Letter to Headquarters, Department of the Army, ATTN: DASG-PSP. Subject: Health hazard Priority research needs, with 1st and 2nd Endorsements. 6 March 1986.

2. Bhattacharyya, M.H., J.H. Stebbings, D.P. Peterson, S.A. Johnson, R. Kumar, B.D. Goun, I. Janssen, and J.E. Trier. 1989. Lead exposures and biological responses in military weapons systems: Aerosol characteristics and acute lead effects among U.S. Army artillerymen. Army Project Order 86PP6821. Argonne National Laboratory, Argonne, IL.

3. Patty's Industrial Hygiene and Toxicology. Volume 2A: Toxicology, 3rd Revised Ed. George D. Clayton and Florence E. Clayton (Ed.) John Wiley and Sons, New York.

4. Landgrigan, P.J., A.S. McKinney, L.C. Hopkins, W.W. Rhodes, Jr., W.A. Price, and D.H. Cox. 1975. Chronic lead absorption, result of poor ventilation in an indoor pistol range. J. Am. Med. Assoc. 234(4):394-397.

5. Brown, J.R. 1983. A survey of the effects of lead on gunners. J.R. Army Med. Corp. 129:75-81.

6. U.S. Army Medical Department Activity. 1985. Medical and health surveillance for M109 howitzer extended life program (HELP) operational test II, 3 June 1985 through 26 July 1985. Ft. Sill, OK.

7. Bhattacharrya, M.H. 1989. Technical Progress Report No. 2. Argonne National Laboratory, Argonne, IL.

8. U.S. Army Environmental Hygiene Agency. 1988. Health hazard assessment report (RCS 388) on the howitzer improvement program (HIP), 69-37-4563-88. Aberdeen Proving Ground, MD.

9. U.S. Army Combat Systems Test Activity. 1982. Determination of airborne lead concentrations in the crew compartment of a M109A2 self-propelled howitzer during firing. CSTA Report No. 83-CC-69. Aberdeen Proving Ground, MD.

10. U.S. Army Environmental Hygiene Agency. 1989. Reassessment of health hazard assessment (HHA) on the howitzer improvement program (HIP). Aberdeen Proving Ground, MD.

11. Title 29, Code of Federal Regulations, part 1910.1025 (Lead).

12. Laboratory Services Branch Test Report, Material Test Directorate, Yuma Proving Ground. 1 February 1989. Subject: Lead Particulate In Air

13. Eller, Peter M. (Editor). 1984. DHHS (NIOSH) Publication 84-100, NIOSH Manual of Analytical Methods, Third Edition. U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering, Cincinnati, Ohio.

14. National Health Laboratories. Protocols: Lead (Heated Graphite Furnace), dated 6/89; Carbon Monoxide, dated 6/89; Free Erythrocyte Protoporphyrins in Whole Blood, Calculation of Equivalent Zinc Protoporphyrin, LS-5 Spectrophotometer, dated 6/89; H-6000 (Hemoglobin, hematocrit, RBC, WBC, red cell indices, platelets and differential white cell count from one EDTA anticoagulated blood sample, dated 9/89. Dallas, TX.

15. Muijser, H., E.M.G. Hoogendijk, J. Hooisma, and D.A.M. Twisk. 1987. Lead exposure during demolition of a steel structure coated with lead based paints. II. Reversible changes in the conduction velocity of the motor nerves in transiently exposed workers. Scand. J. Work Environ. Health 13:56-51.

16. de Jesus, Jr., P.V., I. Hausmanowa-Petrusewicz, and R.L. Barchi. 1973. The effect of cold on nerve conduction of human slow and fast nerve fibers. Neurology (Minneap.) 23:1182-1189.

17. SAS^R Institute. 1985. SAS User's Guide: statistics. 5th Edition. SAS Institute. Cary, NC.

18. Marsh, W.L., D.P. Nelson, and H.M. Koenig. 1983. Free erythrocyte protoporphyrin (FEP) I. Normal values for adults and evaluation of the hematoflurometer. Am. J. Clin. Pathol. 79:655-60.

19. Harrison's Principles of Internal Medicine. Thorn, G.W., R.A. Adams, and E. Braunwald (Eds.). 1977. McGraw-Hill. New York, NY.

20. MIL-STD-1472C, 2 May 1981, Human Engineering Design Criteria for Military Systems, Equipment and Facilities.

21. Menzies, K.T., M.A. Randel, and A.L. Quill. 1989. Evaluation of weapons combustion products in armored vehicles. Final Report, Contract No. DAMD17-86-C-6245. Cambridge, MA. Arthur D. Little, Inc.

22. Amnest, J.L., K.R. Mahaffey, D.H. Cox, and J. Roberts. 1984. Blood lead levels for persons 6 months - 74 years of Age. United States, 1976 - 1980. DHHS Publication No. 82-1250. National Center for Health Statistics, Hyattsville, MD.

23. Creason, J.P., D.I. Hammer, A.V. Colucci, L.P. Priester, and J. Davis. 1976. Blood trace metals in military recruits. Southern Med. J. 69(3):289-93

24. Hodgkins, D.G., D.L. Hinkamp, T.G. Robins, S.P. Levine, M.A. Schork, and W.H. Krebs. 1990. Air-lead particle sizes in battery manufacturing: Potential effects on the OSHA compliance model. Appl. Occup. Environ. Hyg. 5:518-525.

25. Valway, S.E., J.W. Martyny, J.R. Miller, M. Cook, and E.J. Mangione. 1989. Lead absorption in indoor firing range users. Am. J. Public Health 79:1029-32.

26. Griffin, T.B., F. Coulston, H. Wills, J.C. Russell, and J.H. Knelson. 1975. Clinical studies on men continuously exposed to airborne particulate lead. In: Lead. Eds. T.B. Griffin and J.H. Knelson. pp. 221-240. Academic Press, New York, NY.

27. Labreche, F. and A. P'an. 1982. Relationships between three indicators of lead exposure in workers: blood lead, delta-aminolevulinic acid and free erythrocyte protoporphyrin. Int. Arch. Occup. Environ. Hlth. 51:35-44.

28. Boeckx, R.L. 1979. The clinical chemistry of lead poisoning. New approaches to an old problem. Clin. Proc. Child Hosp. Natl. Med. Center 35:216-38.

29. Dally, S., M. Duvelleroy, F. Conso, and E. Fournier. 1980. Simulation d'intoxications chroniques: l'exemple du plomb. Arch. Mal. Prof. 41:129-35.

30. Kononen, D.W. 1991. First-year changes in blood lead and zinc protoporphyrin levels within two groups of occupational lead workers. Am. Ind. Hyg. Assoc. J. 52(4):177-82.

31. Grobler, S.R., R.J. Rossouw, and D. Kotze. 1988. Effect of airborne lead on the blood lead levels of rats. S. African J. Sci. 84:260-62.

32. Hamilton and Hardy's Industrial Toxicology, 4th Ed. 1983. Revised by Asher J. Finkel. John Wright-PSG, Inc., Littleton, MA.

33. Gross, S. 1981. Human oral and inhalation exposures to lead: summary of Kehoe balance experiments. J. Toxicol. Env. Health 8:333-377.

34. Zielhuis, R.L. 1975. Dose-response relationships for inorganic lead. I. Biochemical and Hæmatological Responses. Int. Arch. Occup. Hlth 35:1-18.

35. Verschoor, M., R. Herber, R. Zielhuis, and A. Wibowo. 1987. Zinc protoporphyrin as an indicator of lead exposure: precision of zinc protoporphyrin measurements. Int. Arch. Occup. Environ. Hlth. 59:613-21.

36. Grandjean, P., P.J. Jorgensen, and S. Viskum. 1991. Temporal and interindividual variation in erythrocyte zinc-protoporphyrin in lead exposed workers. Brit. J. Ind. Med. 48:254-257.

37. Harada, K. and H. Miura. 1984. Free erythrocyte protoporphyrin and zinc protoporphyrin as biological parameters for lead poisoning. Int. Arch. Occup. Environ. Hlth. 53:365-77.

38. Kaul, B., G. Slavin, and B. Davidow. 1983. Free erythrocyte protoporphyrin and zinc protoporphyrin measurements compared as primary screening methods for detection of lead poisoning. Clin. Chem. 29(8):1467-70.

39. Lerner, S., P. Gartside, and B. Roy. 1982. Free erythrocyte protoporphyrin, zinc protoporphyrin and blood lead in newly re-exposed smelter workers: a prospective study. Am. Ind. Hyg. Assoc. J. 43:516-19.

40. Kracic, V., D. Prpic-Majic, and S. Telisman. 1980. The relationship between zinc protoporphyrin (ZPP) and "free" erythrocyte protoporphyrin (FEP) in lead-exposed individuals. Int. Arch. Occup. Environ. Hlth. 47:165-77.

41. Alessio, L., P.A. Bertazzi, O. Monelli, and F. Toffoletto. 1976. Free erythrocyte protoporphyrin as an indicator of the biological effect of lead in adult males. III. Behavior of free erythrocyte protoporphyrin in workers with past lead exposure. Int. Arch. Occup. Environ. Hlth. 38:77-86.

42. Kang, H.K. and P.F. Infante. 1983. Determination of blood lead elimination patterns of primary lead smelter workers. J. Toxicol. Env. Health

43. Wildt, K., M. Berlin, and P.E. Isberg. 1987. Monitoring of zinc protoporphyrin levels in blood following occupational lead exposure. Am. J. Ind. Med. 12:384-398.

44. Stankiewicz, A. 1989. The concentration of protoporphyrin IX in workers occupationally exposed to lead. Polish J. Med. Pharm. 2(70):100-2.

45. Hryhorzuk, D.O., M.M. Hogan, K. Mallin, S.M. Hessl, and P. Orris. 1985. The fall of zinc protoporphyrin levels in workers treated for chronic lead intoxication. J. O. M. 27(11):816-20.

46. Seppalainen, A.M. and S. Hernberg. 1980. Subclinical lead neuropathy. Am. J. Ind. Med. 1:413-20.

47. Seppalainen, A.M., S. Hernberg, R. Vesanto, and B. Kock. 1983. Early neurotoxic effects of occupational lead exposure: A prospective study. Neurotox. 4(2):181-92.
48. Schwartz, J., P.J. Landrigan, R.G. Feldman, E.K. Silbergeld, E.L. Baker, Jr., and I.H. von Linden. .1988. .Threshold effect in lead-induced peripheral neuropathy. J. Pediatr. 112:12-17.
49. Yokoyama, K. and S. Araki. 1986. Alterations in peripheral nerve conduction velocity in low and high lead exposure: an animal study. Ind. Health 24:67-74.
50. Murata, K., S. Araki, and H. Aono. 1987. Effects of lead, zinc, and copper absorption on peripheral nerve conduction in metal workers. Int. Arch. Occup. Environ. Health 59:11-20.
51. Parmer, D.L. 1989. Unpublished data from the HIP 155MM crewman exposure study.
52. Feldman, R.G., J. Lewis, and R. Cashins. 1977. Subacute effects of lead-oxide fumes in demolition workers. Lancet 1:89-90.
53. Cullen, M.R., J.M. Robins, and B. Eskenazi. 1983. Adult inorganic lead intoxication: presentation of 31 new cases and a review of recent advances in the literature. Medicine 62:221-47.
54. Landrigan, P.J. 1990. Current issues in the epidemiology and toxicology of occupational exposure to lead. In: Environmental Health Perspectives, Vol. 89. U.S. DHEW.
55. Roels, H., J-P. Buchet, R. Lauwerys, G. Hubermont, P. Bruaux, F. Claeys-Thoreau, A. Lafontaine, and J. van Overschelde. 1976. Impact of air pollution by lead on the heme biosynthetic pathway in school-age children. Arch. Environ. Hlth. 31:310-315.
56. Grandjean, P., B.M. Jensen, S.H. Sando, P.J. Jorgensen, and S. Antonsen. 1989. Delayed blood regeneration in lead exposure: an effect on reserve capacity. Am. J. Public Hlth. 79:1385-1388.
57. Corsi, G. and G. Bartolucci. 1982. Biological monitoring of workers with past lead exposure: Biochemical findings. Scand. J. Work. Environ. Hlth. 8:260-266.
58. Baker, E.L., R.F. White, L.J. Pothier, C.S. Berkey, G.E. Dinse, P.H. Travers, J.P. Harley, and R.G. Feldman. 1985. Occupational lead neurotoxicity: improvement in behavioural effects after reduction of exposure. Brit. J. Ind. Med. 42:507-16.
59. Mantere, P., H. Hanninen, and S. Hernberg. 1982. Subclinical neurotoxic lead effects: two-year follow-up studies with psychological test methods. Neurobehav. Toxicol. Teratol. 4:725-7.
60. Weyandt, T.B. 1992. Evaluation of biological and male reproductive function responses to potential lead exposures in 155 MM howitzer crewmen. Technical Report 9124. U.S. Army Biomedical Research and Development Laboratory, Ft. Detrick, Frederick, MD.
61. Bhattacharyya, M.H. 1990. Technical Progress Report No. 19. Argonne National Laboratory, Argonne, IL.
62. Williamson, A.M. and R.K.C. Teo. 1986. Neurobehavioral effects of occupational exposure to lead. Br. J. Ind. Med. 43:374-380.
63. Moody, L., J. Arezzo, and D. Otto. 1986. Screening occupational populations for asymptomatic or early peripheral neuropathy. J. O. M. 28(10):975-86.
64. Benignus, V.A., K.E. Muller, and C.M. Mallott. 1990. Compensatory tracking in humans with elevated carboxyhemoglobin. Neurotoxicol. Teratol. 12:105-10.
65. Benignus, V.A. and M.J. Hazucha. 1992. Experimental design and instrumentation for a field experiment. U.S. Environmental Protection Agency, U.S. Army Research and Development Command Project Order 81PP1812.

APPENDIX A

U.S. ARMY LEAD EXPOSURE AND HEALTH QUESTIONNAIRE

1. Name: ______________ / ______________ / ______________
   Last First Middle

2. Social Security Number: |__|__|__|-|__|__|-|__|__|__|__|

3. MOS: |__|__|__|__|__|__|__|

4. Date of Interview: |__|__|__|__|__|__|
   M M D D Y Y

5. Interviewer: ______________________ |__|__|

6. Interview Start Time: ___:___ a.m. p.m. end ___:___ a.m. p.m.

7. Sex (by observation)
   1 = male
   2 = female

8. Race (by observation)
   1 = white
   2 = black
   3 = Amer. Indian
   4 = Oriental
   5 = Spanish surname
   6 = Pacific Islander
   9 = unknown

I'D LIKE TO TALK WITH YOU FOR A FEW MINUTES ABOUT YOUR HEALTH, LIFE STYLE, AND JOBS. ALL INFORMATION IS CONFIDENTIAL AND WILL ONLY BE RELEASED IN A GROUP FORM WITHOUT NAMES OR IDENTIFIERS.

9. What is your birthdate? |__|__|__|__|__|__|
   M M D D Y Y

10. What is your marital status?
    1 = never married
    2 = married
    3 = widowed
    4 = divorced
    5 = separated
    6 = other
    9 = don't know

11. What was the last grade of formal education you completed?
    1 = <8th grade
    2 = high school, incomplete
    3 = high school graduate/GED
    4 = college, incomplete
    5 = college graduate
    6 = graduate school
    9 = don't know

NOW I'D LIKE TO ASK SEVERAL QUESTIONS ABOUT YOUR GENERAL HEALTH.

12. Are you right now under a doctor's care or taking any prescription medicines on a regular basis?
    1 = no
    2 = yes
    9 = unknown
    If yes, diagnosis ______________________
    treatment/medicine ______________________

13. Have you experienced any of the following symptoms in the last month?

1 = no
2 = yes

a. loss of appetite.................. ☐
b. weight loss........................ ☐
c. fatigue............................ ☐
d. nausea and/or vomiting.......................... ☐
e. diarrhea........................... ☐
f. fever.............................. ☐
g. abdominal pain..................... ☐
h. sore throat........................ ☐
i. cough.............................. ☐
j. changes in skin pigmentation.................... ☐
k. white lines across fingernails.............. ☐
l. pins and needles, numbness or pain of the limbs..................... ☐
m. weakness of the muscles of the limbs............ ☐
n. pain or soreness of the mouth, nose or eyes......... ☐
o. skin irritation.................... ☐
p. accidental injury (breaks, burns, etc.)............ ☐
q. hospitalization.................... ☐

14. Have you ever been told by a doctor that you have any of the following?

1 = no
2 = yes

a. anemia............................. ☐
b. diabetes........................... ☐
c. nerve damage....................... ☐

15. Have you ever

a. broken your arm or leg?............ ☐
b. fractured your arm or leg?......... ☐
c. badly cut or punctured your arm or leg?................ ☐

IF YES - Specify LIMB(S)____________________
Details:____________________

16. Have you ever smoked as many as five packs of cigarettes, that is, as many as 100 cigarettes during your entire life?

1 = no
2 = yes ☐

17. Do you now smoke cigarettes?

1 = no
2 = yes ☐

18. If you are a current or ex-smoker,
   a. How many cigarettes do (did) you smoke per day?

____
Actual Response

1 = < 1/2 pack/day (1-5 cig./day)
2 = ≈ 1/2 pak/day (6-14 cig./day)
3 = ≈ 1 pak/day (15-25 cig./day)
4 = ≈ 1 1/2 packs/day (26-36 cig./day)
5 = > 2 packs/day (35+ cig./day)
9 = N/A

   b. How old were you when you first started smoking? (regularly)

   ____ Age

   c. How old were you when you last gave up smoking, if you no longer smoke?

   ____ Age

____
Actual Response

99 = N/A

NOW I'D LIKE TO ASK YOU ABOUT HOW MUCH ALCOHOL YOU DRINK. FIRST I'LL ASK ABOUT DURING THE WEEK AND THEN ABOUT THE WEEKENDS.

19. On average, how many alcoholic drinks do you consume during the work week, that is, Mondays until you get off duty on Fridays. Count each beer and standard drink as 1 drink. [If an individual has a nonstandard workweek, note below.]

(Read all choices)

____
Nonstandard workweek

1 = 1 or less drinks
2 = 2 to 12 drinks
3 = 13 to 24 drinks
4 = 25 to 48 drinks
5 = 49 to 100 drinks

1. On average, how many alcoholic drinks do you consume during a usual weekend, from the time you get off duty on Fridays, through Sundays?

(If individual works weekends, this applies to their days off)

____
Nonstandard workweek

1 = 1 or less drinks/weekend
2 = 2 to 12 drinks/weekend
3 = 13 to 24 drinks/weekend
4 = 25 to 48 drinks/weekend
5 = 49 to 100 drinks/weekend

W I'D LIKE TO ASK A FEW QUESTIONS ABOUT YOUR WORK.

. Your MOS is ______________; how would you describe the job to a civilian?

____

22. During the last 6 weeks have you been

a. involved in the painting or preparation for painting of buildings or vehicles? 1 = no 2 = yes

b. used solder?

c. spent time on indoor firing range? If yes, no. of hours ________ When ________

d. were present during weapons firing outdoors?

Specify weapon(s) and number of hours on the range		Hours	When
	a. ________	/	/
	b. ________	/	/
	c. ________	/	/
	d. ________	/	/
	e. ________	/	/

23. Do you have a part-time job in addition to your regular job? 1 = no 2 = yes

IF YES, Specify ________ / ________ Hrs/Wk

24. What type of work did you do before you entered the Army for this tour of duty?

For any previous tour of duty? (Continue on rear if necessary)

Industry	Job Description	Year(s)	
		From	To

25. Where did you live before you entered the military for this tour of duty?

1 = farm
2 = non-farm rural
3 = small town/town
4 = suburban
5 = city
9 = unknown

City/Town	State	From	To	Area Type

26. What MOS's and duty types have you had since entering the service?

MOS	Duty	Dates	
		To	From

APPENDIX B

FIELD SAMPLING DATA SHEET

SCENARIO 2 GUN ID NO. A RUN 8 DATE 8 Jul 89

PUMP			TIME		REMARKS
SAMPLE No.	CODE	PUMP NO.	ON	OFF	
2A8 2901	S	S00072	1249	2150	
2A8 8071	S	S00076	1249	2159	
2A8 3132	S	S00215	1403	2145	
2A8 3883	S	S00233	1404	2156	
2A8 0156	S	S00254	1405	2146	
2A8 2498	S	S00276	1406	2153	

COMMENTS:

Pump codes - G - Gillan
D - Dupont
S - SKC

APPENDIX C

Quality Control Results for Analysis of Lead Air Samples

TABLE C-1

Precision of Analysis for a 1.00 ppm Quality Control Sample by Atomic Absorption

Date	Analysis
August 28, 1989	1.03
"	1.01
August 29, 1989	0.99
"	1.03
August 30, 1989	0.99
"	0.97
August 31, 1989	1.02
"	0.98
September 1, 1989	0.99
September 5, 1989	0.99
	Mean = 1.00
	$\sigma_n = 0.02$; $\sigma_{n-1} = 0.02$

TABLE C-2

Field Blank Data for Air Lead Analysis

Analyzed Date	Blank (ppm - Pb)
August 16, 1989	0.03; 0.04
August 16, 1989	0.16; 0.02
August 18, 1989	-0.03; -0.05
August 21, 1989	0.04; 0.02
August 22, 1989	0.00
August 23, 1989	0.01
August 23, 1989	0.01
August 24, 1989	0.02
August 25, 1989	0.01
August 28, 1989	0.01; 0.00
August 29, 1989	0.02

Note: Field blanks are filters which were loaded into spare cassettes, pre-calibrated, loaded unto spare pumps, taken to field locations and not used. Field blanks assess the potential for contamination during handling by sample personnel during loading, calibration and field transport.

TABLE C-3

Spike Data for Air Lead - Atomic Absorption Analysis

Date	Lab No.	Sample No.	Sample Pb	Added Pb	Found Pb	% Recovery
Aug 14	5	1A01-2901	0.11	2.00	2.10	>99
Aug 16	15	1A07-3883	0.02	1.00	1.03	103
Aug 18	13	1A10-8071	0.12	1.00	1.09	97
Aug 17	13	1A10-8071	0.10	1.00	1.09	>99
Aug 21	23	1B01-4983	0.18	1.00	1.18	100
Aug 22	6	1B03-8868	0.17	1.00	1.16	>99
Aug 23	24	1B07-3077	0.10	1.00	1.11	101
Aug 23	21	1B10-4983	0.20	1.00	1.21	101
Aug 24	1	1B10-8868	0.16	1.00	1.16	100
Aug 25	12	1C04-8618	0.25	1.00	1.23	98

Note: 1. Samples were analyzed from 50 ml. volumes; 1 ppm Pb $\simeq$ 0.05 mg Pb/filter.
2. An acceptable recovery was considered to be 95%.

TABLE C-4

Comparison of Whole Filter versus Half Filter Data

Date	Sample No.	PPM Pb	PPM difference	mg Pb/filter difference
Sept 1 Sept 5	2A04-8071	0.49 0.44	0.05	<0.01
Sept 5 Aug 30	1D08-0897	0.10 0.03	0.07	<0.01
Sept 5 Aug 31	1D09-0897	1.27 1.37	0.10	<0.01
Sept 5 Aug 31	1D10-8549	2.49 2.61	0.12	<0.01
Sept 5 Aug 31	1D13-0897	0.15 0.05	0.10	<0.01

APPENDIX D

Comparisons Of Wind Direction And Speed With Howitzer Firing Azimuth

Wind direction plus or minus a 30° quadrant on either side of the reported wind direction for that time period is compared with the gun azimuth. Gun sections (labeled A, B, C, D) are always deployed from left to right relative to the gun azimuth. A tail wind blows in the same direction (by definition ± 30°) as the weapon azimuth. A head wind blows in the opposite direction (± 30°). All other directions are labeled quartering winds.

HIPs

Exercise I (Table D-1)

Windy periods appeared to be almost equally interspersed with periods of calm. When the wind was blowing, it tended to be away from or perpendicular to the gun azimuth. Quartering, or perpendicular wind periods were equally divided between periods of wind blowing to the north early in the exercise (from BCD to A) and to the southwest late in the exercise (from A to BCD). In periods 1 and 4 we might have had some expectation that FAASV crews would receive higher concentrations due to the wind blowing muzzle emissions back towards the FAASVs. Emissions from gun A would blow towards gun B in periods 9 and 10; while emissions from gun B would blow towards gun A in periods 1 and 4, although these latter observations would be complicated by emissions from guns C and D.

TABLE D-1

HIP Exercise I Meteorology

Date	Period	Time	Pointing Azimuth (°)	±30°	Wind Direction (°)	Wind Speed (Kts)	Wind/ Howitzer Orientation
25 June							
	Pd 1	0700	76	46-106	00	00	Calm
		1117	76	46-106	00	00	Calm
		1234	76	46-106	15	04	Quartering
		1301	70	40-100	11	03	Quartering
		1509	70	40-100	08	03	Head
	Pd 2	1754	70	40-100	10	05	Head
		1848	65	35-95	12	03	Quartering
26 June							
	Pd 3	0210	82	52-112	00	00	Calm
		0610	79	49-109	00	00	Calm
	Pd 4	0610	79	49-109	13	01	Quartering
		1218	76	46-106	16	01	Quartering
		1235	76	46-106	09	03	Head
		1309	62	32-92	08	02	Quartering

TABLE D-1 (Cont.)

Date	Period	Time	Pointing Azimuth (°)	$\pm30°$	Wind Direction (°)	Wind Speed (Kts)	Wind/ Howitzer Orientation
28 June							
	Pd 9	0038	76	46-106	00	00	Calm
	Pd 10	0632	73	3-103	01	02	Quartering
		1040	82	52-112	02	06	Quartering
		1154	79	49-109	02	04	Quartering

<u>Exercise II</u> (Table D-2)

All periods contained quartering winds. These winds appeared to be divided between wind blowing to the south early in the period (from A to BCD) and to the north late in the period (from BCD to A). Exposure estimates for gun A would be greater than B in period 11 if due to wind factors alone and vice versa for B in periods 3 and 4.

TABLE D-2

HIP Exercise II Meteorology

Date	Period	Time	Pointing Azimuth (°)	$\pm30°$	Wind Direction (°)	Wind Speed (Kts)	Wind/ Howitzer Orientation
6 July							
	Pd 2	2320	76	46-106	00	00	Calm
7 July							
	Pd 3	0430	73	43-103	36	02	Quartering
	Pd 4	0430	73	43-103	36	02	Quartering
		0510	76	46-106	36	02	Quartering
		1249	73	43-103	05	06	Head
		1340	79	49-109	11	05	Quartering
9 July							
	Pd 10-11	1139	110	80-140	22	08	Quartering
		1422	101	71-131	21	06	Quartering
		2005	107	77-137	21	08	Quartering
		2314	98	68-128	15	03	Quartering
		0137	248	218-278	16	10	Tail

Exercise III (Table D-3)

The wind consistently quartered to the south, with gun emissions from A blowing towards BCD. Under these circumstances A section crew exposure concentrations would be expected to be higher than B.

TABLE D-3

HIP Exercise III Meteorology

Date	Period	Time	Pointing Azimuth (°)	±30°	Wind Direction (°)	Wind Speed (Kts)	Wind/ Howitzer Orientation
19 July-20 July							
	Pd 1-2	1600	73	43-103	36	13	Quartering
		1846	76	46-106	36	04	Quartering
		1858	76	46-106	36	04	Quartering
		1927	76	46-106	36	04	Quartering
		1943	73	43-103	36	04	Quartering
		2207	79	49-109	35	02	Quartering
		2325	56	26-86	00	00	Calm
		0431	59	29-89	34	03	Quartering
	Pd 3	0645	73	43-103	35	05	Quartering
		0842	73	43-103	36	08	Quartering
		0859	73	43-103	36	08	Quartering
		1046	73	43-103	01	12	Quartering
		1216	73	43-103	03	15	Quartering
		1314	73	43-103	03	12	Quartering
		1436	79	49-109	02	11	Quartering
21 July							
	Pd 4-5	2158	68	38-98	06	03	Head
		2312	87	57-117	00	00	Calm
		0634	82	52-112	36	02	Quartering
	Pd 6	0634	82	52-112	36	02	Quartering
		0855	82	52-112	16	02	Head
		1101	82	52-112	17	07	Head
		1242	82	52-112	13	05	Quartering
		1401	76	46-106	29	02	Tail

M109A3s

Exercise I (Table D-4)

The wind was calm or perpendicular to the gun azimuth most of the time, with two periods (Period 1 and Period 10) in which the wind blew the barrel emissions towards the crew at least part of the time. Also during periods 1 and 4, quartering winds would have blown emissions from section D toward sections ABC in the battery. During one other period of quartering winds, section ABC emissions would have blown toward section D (Period 10). If wind would have been a factor during these periods, we might expect FAASV crews to have higher values during Periods 1 and 10 and Section C higher than section D in periods 1 and 4. Comparison of sections C and D for Period 10 would be complicated by the contribution of sections A and B, which were not monitored in this study.

TABLE D-4

M109A3 Exercise I Meteorology

Date	Period	Time	Pointing Azimuth (°)	±30°	Wind Direction (°)	Wind Speed (Kts)	Wind/ Howitzer Orientation
25 June							
	Pd 1	1032	79	49-109	00	00	Calm
		1200	87	57-117	18	05	Quartering
		1329	82	52-112	11	03	Tail
	Pd 2	1750	71	41-101	12	07	Quartering
	Pd 3	0250	84	54-114	00	00	Calm
	Pd 4	0809	84	54-114	13	01	Quartering
		1004	82	52-112	17	02	Quartering
	Pd 9	0415	84	54-114	00	00	Calm
	Pd 10	1144	82	52-112	02	04	Quartering
		1255	76	46-106	05	08	Tail

Exercise II (Table D-5)

The wind was predominantly blowing in the opposite direction as the gun azimuth, except for two periods when the emissions were almost perpendicular to the gun azimuth. During two periods, emissions from section D would have blown towards sections ABC (Periods 10 and 11) and during Period 4 emissions could have blown from ABC to D. Period 3 was calm. We might estimate from these observations that section C would have higher values than section D during Period 4 and that FAASV crews would exhibit higher values than gun crews during periods 1, 2, 4, and 5.

TABLE D-5

M109A3 Exercise II Meteorology

Date	Period	Time	Pointing Azimuth (°)	±30°	Wind Direction (°)	Wind Speed (Kts)	Wind/ Howitzer Orientation
6 July							
	Pd 2	1215	84	54-114	30	02	Quartering
		1459	82	52-112	11	05	Tail
		1627	79	49-109	09	06	Tail
		1630	82	52-112	09	06	Tail
	Pd 3	0005	84	54-114	00	00	Calm
	Pd 4	0440	82	52-112	36	02	Quartering
		0959	84	54-114	06	05	Tail
	Pd 10	0030	65	35-95	13	02	Quartering
		0154	79	49-109	22	08	Quartering
		0618	84	54-114	15	04	Quartering
	Pd 11	1131	79	49-109	22	08	Quartering

Exercise III (Table D-6)

The wind was almost always quartering during this exercise, with one period being calm at times (Period 3). All quartering winds would have blown emissions from section C to D, except perhaps for period 4 and portions of period 3, which was blowing more directly to the rear. These wind patterns would suggest that air lead concentrations for section C in periods 1, 3, 6 and maybe 4 would be higher than section D.

TABLE D-6

M109A3 Exercise III Meteorology

Date	Period	Time	Pointing Azimuth (°)	±30°	Wind Direction (°)	Wind Speed (Kts)	Wind/ Howitzer Orientation
19 July							
	Pd 1	1600	84	54-114	36	13	Quartering
20 July							
	Pd 3	0143	84	54-114	00	00	Calm
		0817	84	54-114	36	07	Quartering
	Pd 4	1240	79	49-109	03	12	Quartering
21 July							
	Pd 5	0041	79	49-109	35	02	Quartering
	Pd 6	0839	79	49-109	35	04	Quartering

APPENDIX E

Air Concentration Estimation Procedures

1. Criteria for a valid sample.

a. A sampling ensemble is returned without a flow-interrupt light on the pump, a post-sample calibration of approximately 2.0 l/min, and an intact filter cassette.

b. A sampling ensemble is returned with the pump off or a flow-interrupt light on the pump and an intact filter cassette. The filter has no detectable lead, firing records indicate no high-zone rounds were fired, and the sampled individual's peers have no detectable lead on their filters.

2. Criteria for a sample suitable for developing an estimate:

a. The filter data is within the range of peer filter data. Pump is off or does not post-calibrate. Flow data used for estimate is mean of peers.

b. The filter has negative or low lead values and the pump has questionable flow data. Peers have lead filter data and records show that high-zone rounds were fired. Both lead filter and flow data are estimated from mean of peers, but for not more than two periods out of each exercise (each exercise typically had 12 - 13 periods, of which 5 - 6 were periods in which high-zone rounds were fired).

3. Summary of estimates:

Subject	Period	Fault	Correction
2AB	I.11	pump off	mean flow of peers
4AB	II.5	inad. filter/flow data	mean filter/flow data of peers
4AB	III.2	inad. filter/flow data	mean filter/flow data of peers
4AB	III.6	pump off	mean flow of peers
5AB	I.1	pump off	mean flow of peers
5AB	II.11	inad. filter/flow data	mean filter/flow data of peers
6AB	I.10	inad. filter/flow data	mean filter/flow data of peers
6AB	III.6	inad. filter/flow data	mean filter/flow data of peers
8AB	I.4	inad. filter/flow data	mean filter/flow data of peers
8AB	III.2	pump off	mean flow of peers
9AB	II.11	inad. filter/flow data	mean filter/flow data of peers
9AB	III.3	inad. filter/flow data	mean filter/flow data of peers
10AB	III.6	pump off	mean flow of peers
13AB	I.1	inad. filter/flow data	mean filter/flow data of peers
13AB	I.9	pump off	mean flow of peers
13AB	II.11	inad. filter/flow data	mean filter/flow data of peers
16AB	II.11	inad. filter/flow data	mean filter/flow data of peers
17AB	I.10	pump off	mean flow of peers
18AB	I.9	inad. filter/flow data	mean filter/flow data of peers
18AB	II.3	inad. filter/flow data	mean filter/flow data of peers
18AB	III.2	inad. filter/flow data	mean filter/flow data of peers
19AB	III.6	inad. filter/flow data	mean filter/flow data of peers
20AB	III.3	inad. filter/flow data	mean filter/flow data of peers
22AB	II.2	pump off	mean flow of peers
22AB	III.5	inad. filter/flow data	mean filter/flow data of peers
23AB	III.6	pump off	mean flow of peers
25AB	I.4	inad. filter/flow data	mean filter/flow data of peers
25AB	III.1	pump off	mean flow of peers
26AB	I.9	inad. filter/flow data	mean filter/flow data of peers
26AB	II.5	inad. filter/flow data	mean filter/flow data of peers

Subject	Period	Fault	Correction
28AB	I.1	inad. filter/flow data	mean filter/flow data of peers
28AB	I.4	inad. filter/flow data	mean filter/flow data of peers
29AB	I.3	pump off	mean flow of peers
29AB	I.10	pump off	mean flow of peers
30AB	I.9	inad. filter/flow data	mean filter/flow data of peers
31AB	I.2	pump off	mean flow of peers
31AB	I.3	pump off	mean flow of peers

APPENDIX F

Concentration/Time Product for Air Lead Exposure for HIP Firing Exercises
(mg-hr/m^3)

Weapons System / Section / Vehicle / Subject	Period			
	Exercise I	Exercise II	Exercise II	Total
HIPs				
Section B				
Gun				
2AB	41.28	63.59	16.05	120.92
20AB	45.21	76.86	86.76*	208.83
29AB	37.93*	44.20	76.73	158.86
31AB	46.27*	78.15	92.65	217.07
FAASV				
6AB	53.89*	--	28.82*	--
14AB	67.06	44.61	34.91	146.58
Section C				
Gun				
16AB	--	72.32*	32.45	--
24AB	140.75	61.53	45.21	247.49
28AB	169.92*	144.17	29.11	343.20
30AB	133.47*	86.58	48.68	268.73
FAASV				
5AB	116.54*	45.79*	32.34	194.67
17AB	112.79*	88.81	19.22	220.82
18AB	113.70*	57.65*	19.20*	190.55
22AB	100.00	57.98*	22.09*	180.07
A3s				
Section A				
Gun				
4AB	82.19	211.81*	223.15*	517.15
7AB	118.86	225.70	192.86	537.42
9AB	201.28	225.10*	251.05*	677.43
27AB	155.45	--	167.35	--
FAASV				
3AB	151.26	158.25	--	--
8AB	151.21*	151.80	165.60*	468.61
23AB	93.21	--	185.60*	--
26AB	160.68*	108.35*	117.17	386.20

APPENDIX F (Cont.)

Weapons System Section Vehicle Subject	Period			
	Exercise I	Exercise II	Exercise II	Total
Section D				
Gun				
1AB	183.50	132.89	114.74	431.13
12AB	153.66	--	120.94	--
19AB	104.67	131.78	113.35*	349.80
21AB	127.24	115.13	103.96	346.33
FAASV				
10AB	132.11	85.82	102.74*	320.67
11AB	89.29	--	93.25	--
13AB	91.64*	77.53*	94.27	263.44
15AB	32.73	--	41.98	--
25AB	104.98*	89.44	89.15*	283.57

-- insufficient or missing data
* one or two 8-hr TWA periods have been estimated

APPENDIX G, TABLE G-1

Individual Blood Parameters for HIP Crewmen

SUBJECT	SEC	BASELINE Mar 20-24 PbB	FEP	Hct	PRE TEST 1 23 June PbB	FEP	Hct	POST TEST 1 29 June PbB	FEP	Hct	POST TEST 2 10 July PbB	FEP	Hct	POST TEST 3 24 July PbB	FEP	Hct	8 WEEKS POST 18-21 Sep PbB	FEP	Hct
2AB	B	4	11	43.3	17	18	42.6	16	19	39.6	20	21	40.5	17	33	42.8	10	13	40.1
5AB	C				20	23	43.8	11	27	42.6	25	37	41.9	27	22	42.9	16	22	45.3
6AB	B	5	18	45.8	20	19	45.2	26	24	42.1	23	20	40.6	21	36	42.1	12	17	42.9
14AB	B				17	21	47.9	21	30	45.7	23	30	43.0	18	32	49.0	12	17	44.6
16AB	C	6	18	45.4	20	19	45.1	22	20	41.5	32	23	41.7	29	23	44.4	17	16	47.4
17AB	C	5	18	45.1	17	21	44.8	19	20	41.2	19	28	43.6	20	21	46.9	10	18	45.4
18AB	C				11	24	44.6	12	34	43.2	18	34	40.7	18	27	46.1	9	18	45.6
20AB	B	4	22	44.9	14	24	46.9	9	32	42.4	18	27	42.1	20	32	44.3			
22AB	C	1	24	43.0	12	27	41.2	24	31	39.4	16	28	39.5	13	33	43.1	6	22	43.5
24AB	C	9	24	45.5	19	34	41.3	25	31	43.9	28	44	44.5	25	33	44.6	15	21	45.5
28AB	C	7	21	47.4	13	23	46.5	12	23	43.1	19	28	43.9	17	33	47.1	9	19	44.4
29AB	B	3	27	47.1	11	31	47.2	19	36	45.5	18	32	45.1	19	40	46.3	15	28	47.1
30AB	C	3	19	46.9	13	20	45.0	23	19	43.7	24	21	43.4	17	24	45.1			
31AB	B	6	21	49.0	20	27	47.9	24	27	44.7	25	29	45.1	21	31	47.6			
32B	A	6	14	46.7										19	29	44.3	11	23	48.5
33B	D	5	38	45.1										24	33	47.2	13	18	44.8
34B	D													18	26	47.9			
35B	D	14	23	47.3										23	22	47.2	11	19	46.9
36B	A													20	41	45.4			
37B	D													21	32	44.9	13	20	42.3
38B	D													21	33	46.9	14	18	47.9
39B	D	7	22	45.5										30	44	46.0	18	21	49.3
40B	A	6	18	49.8										21	28	48.3			
41B	D	8	19	49.3										25	31	45.5			
42B	A													21	34	43.4	15	19	50.4
43B	A													14	20	44.2	14	28	42.1
44B	A	6	20	46.7										15	26	38.7	11	18	47.5
45B	D	5	20	46.8										15	29	43.3	12	21	45.5
46B	A	5	12	46.6										27	30	43.0			
49B	A	5	23	44.7										14	24	43.2			

SEC-Section; PbB-blood lead (μg/dl); FEP-free erythrocyte protoporphyrin (μg/dl); Hct-hematocrit (%)
--AB = lead exposure study subjects; --B = medical surveillance subjects

APPENDIX G, TABLE G2

Individual Blood Parameters for M109A3 Crewmen

SUBJECT	SEC	BASELINE Mar 20-24 PbB	FEP	Hct	PRE TEST 1 23 June PbB	FEP	Hct	POST TEST 1 29 June PbB	FEP	Hct	POST TEST 2 10 July PbB	FEP	Hct	POST TEST 3 24 July PbB	FEP	Hct	8 WEEKS POST 18-21 Sep PbB	FEP	Hct
1AB	D	6	24	45.4	11	23	44.3	16	40	45.5	17	41	43.1	17	44	46.3	6	33	45.3
3AB	A	5	36	44.0	18	29	43.3	18	30	42.2	23	36	42.0	25	40	46.0	12	29	43.2
4AB	A	5	24	45.7	15	23	47.1	22	26	45.0	24	29	43.6	24	29	47.8	13	19	44.0
7AB	A	4	38	43.4	16	27	45.8	24	34	42.7	34	34	42.8	24	44	45.2	15	29	33.9
8AB	A	6	30	42.6	11	24	49.5	21	22	45.6	29	28	45.6	33	29	46.5	15	28	47.6
9AB	A	4	29	41.9	23	24	44.1	22	36	44.4	34	24	43.2	37	30	44.5	18	20	47.4
10AB	D				16	27	42.6	14	41	40.0	23	33	40.4	20	34	44.6	10	51	45.6
11AB	D	4	34	44.2	10	19	44.7	22	24	42.6	18	36	43.9	15	29	44.5	10	19	47.7
12AB	D	4	39	45.2	12	19	45.2	23	24	44.7	22	27	46.7	14	32	44.8	9	29	47.8
13AB	D	4	32	42.3	8	21	42.9	23	23	40.5	25	30	42.1	22	33	44.0	9	36	43.2
15AB	D	4	25	41.0	10	17	45.0	17	24	40.5	15	22	40.2	13	32	43.9	10	18	44.1
19AB	D				18	18	42.6	15	24	41.8	24	24	43.3	21	22	44.6	11	30	44.0
21AB	D	5	27	42.7	15	16	39.9	17	24	41.8	31	26	42.3	17	24	44.2	15	34	44.5
23AB	A	5	26	46.4	17	22	48.1	21	22	45.1				17	27	48.4	13	33	45.4
25AB	D	3	40	46.6	16	23	45.2	20	23	45.9	21	33	47.0	21	29	48.3	12	23	47.4
26AB	A	5	34	44.1	13	26	46.5	20	38	45.9	23	33	44.7	25	34	46.2	8	–	–
27AB	A&B	3	49	40.4	24	36	50.6	25	34	47.3	31	38	47.9	30	46	50.8	14	28	50.4
48B	B	4	36	44.5										21	30	44.1	14	27	45.1
49B	C	3	44	45.9										30	24	46.2	16	16	46.9
50B	B	5	24	44.1										32	27	43.3	16	22	43.8
51B	C	6	46	45.1										16	33	45.1	9	24	42.7
52B	A	6	17	42.8										38	29	44.0	21	16	44.6
53B	C	3	31	41.8										16	41	42.9	9	24	45.0
54B	C	4	30	44.2										30	29	43.0	19	24	45.0
55B	C	6	26	45.9										35	31	48.2	15	24	50.7
56B	A	6	30	48.2										24	44	49.6	13	26	47.3
57B	C	4	31	45.4										22	38	45.6	15	22	46.4
58B	B	4	19	44.6										24	21	45.5	11	23	44.4
59B	B	5	28	45.9										19	23	41.9	11	26	45.3
60B	?	6	13	41.1										17	17	34.3			
61B	C	3	32	49.5										16	30	47.1	11	22	45.6
62B	C	4	31	45.3										23	37	42.6	10	24	45.2
63B	B	5	30	41.4										26	41	41.1	14	23	42.3

SEC-Section; PbB-blood lead ($\mu g/dl$); FEP-free erythrocyte protoporphyrin ($\mu g/dl$); Hct-hematocrit (%)
--AB = lead exposure study subjects; --B = medical surveillance subjects

APPENDIX G, TABLE G3

Individual Blood Carboxyhemoglobin and Hemoglobin Parameters for HIP Crewmen

SUBJ	SMOKE	SEC	BASELINE Mar 20-24 COHb	BASELINE Mar 20-24 Hb	PRE TEST 1 23 June COHb	PRE TEST 1 23 June Hb	POST TEST 1 29 June COHb	POST TEST 1 29 June Hb	POST TEST 2 10 July COHb	POST TEST 2 10 July Hb	POST TEST 3 24 July COHb	POST TEST 3 24 July Hb	8 WEEKS POST 18-21 Sep COHb	8 WEEKS POST 18-21 Sep Hb
2AB	Y	B	<5	13.8	<5	13.7	6	12.8	6	13.4	10	13.9	<5	13.1
5AB	N	C	--	--	<5	14.3	<5	14.0	<5	13.6	<5	14.1	<5	15.1
6AB	N	B	<5	15.5	<5	14.8	<5	13.8	10	13.4	<5	13.9	<5	14.5
14AB	Y	B	<5	16.2	<5	15.9	13	15.6	10	14.7	<5	15.8	<5	14.9
16AB	N	C	<5	14.9	9	14.5	<5	14.0	13	14.3	<5	14.7	<5	15.9
17Ab	Y	C	<5	15.3	<5	14.6	<5	13.5	14	14.6	10	15.7	<5	15.1
18AB	N	C	--	--	<5	14.7	12	14.4	14	13.7	15	14.7	<5	15.3
20AB	N	B	<5	15.1	<5	15.5	<5	14.2	14	14.2	15	14.8	--	--
22AB	N	C	<5	14.6	<5	13.6	12	13.1	<5	13.3	<5	13.9	<5	14.5
24AB	N	C	<5	14.9	<5	13.6	12	14.6	10	14.9	10	14.8	<5	15.3
28AB	Y	C	<5	16.2	<5	15.5	<5	14.4	15	15.0	10	16.0	<5	15.3
29AB	Y	B	<5	15.9	8	15.2	<5	15.1	14	15.0	15	15.6	<5	15.1
30AB	Y	C	<5	15.8	<5	15.0	<5	14.9	9	15.0	15	15.3	--	--
31AB	N	B	<5	16.3	<5	15.7	<5	14.9	8	14.8	10	15.9	<5	16.3
32B	-	A	<5	15.9							10	14.4	<5	15.0
33B	-	D	<5	15.2							<5	15.6	--	--
34B	-	D	-	--							13	16.2	<5	15.6
35B	-	D	<5	15.9							13	15.8	--	--
36B	-	A	--	--							15	14.6	<5	13.6
37B	-	D	--	--							15	15.0	<5	15.8
38B	-	D	--	--							15	15.2	<5	16.5
39B	-	D	<5	14.8							15	14.8	--	--
40B	-	A	<5	16.9							15	16.2	--	--
41B	-	D	<5	16.1							5	15.2	<5	16.6
42B	-	A	--	--							10	14.2	<5	13.9
43B	-	A	--	--							<5	14.8	<5	15.8
44B	-	A	<5	15.1							10	12.7	5	14.9
45B	-	D	<5	16.0							10	14.7	--	--
46B	-	A	<5	15.2							13	14.1	--	--
49B	-	A	<5	15.1							15	14.9	<5	15.4

SUBJ- Subject identification code; SMOK- smoker, yes or no; COHb - (%); Hb - (g/dl).

APPENDIX G, TABLE G4

Individual Blood Carboxyhemoglobin and Hemoglobin Parameters for M109A3 Crewmen

SUBJ	SMOKE	SEC	BASELINE Mar 20-24 COHb	BASELINE Mar 20-24 Hb	PRE TEST 1 23 June COHb	PRE TEST 1 23 June Hb	POST TEST 1 29 June COHb	POST TEST 1 29 June Hb	POST TEST 2 10 July COHb	POST TEST 2 10 July Hb	POST TEST 3 24 July COHb	POST TEST 3 24 July Hb	8 WEEKS POST 18-21 Sep COHb	8 WEEKS POST 18-21 Sep Hb
1AB	Y	D	<5	15.2	<5	14.4	9	15.3	15	14.5	15	15.5	<5	15.0
3AB	N	A	<5	14.8	<5	14.6	6	13.9	6	13.7	10	14.9	<5	14.3
4AB	Y	A	<5	15.5	<5	16.1	<5	15.2	12	14.4	15	15.7	<5	15.1
7AB	N	A	<5	14.7	<5	15.2	<5	14.2	10	14.3	13	14.5	<5	10.0
8AB	Y	A	<5	14.5	<5	16.8	8	15.4	15	15.6	15	15.2	<5	15.9
9AB	Y	A	<5	14.2	<5	14.8	<5	14.8	15	14.4	15	14.6	<5	16.1
10AB	N	D	--	--	7	13.5	<5	13.3	10	13.7	15	14.4	<5	15.1
11AB	N	D	<5	14.7	8	14.8	<5	14.3	9	14.5	10	14.9	<5	15.8
12AB	Y	D	<5	15.2	<5	14.9	10	15.0	10	16.1	15	14.7	<5	16.0
13AB	N	D	<5	14.2	<5	14.1	<5	13.6	12	14.1	<5	14.6	<5	14.3
15AB	N	D	<5	13.4	<5	14.8	<5	13.3	13	13.5	10	13.8	<5	14.9
19AB	Y	D	--	--	<5	14.7	<5	14.2	11	14.1	15	14.5	<5	14.7
21AB	N	D	<5	14.0	<5	12.5	<5	13.8	10	13.1	15	13.8	<5	14.4
23AB	N	A	<5	15.7	<5	16.2	<5	15.2	--	--	15	15.8	<5	15.1
25AB	N	D	<5	15.8	<5	15.2	<5	15.5	12	16.0	10	15.8	<5	16.0
26AB	N	A	<5	15.2	<5	15.5	<5	15.3	<5	14.9	10	15.6	--	--
27AB	N	A&B	<5	15.9	<5	16.6	<5	15.7	<5	15.8	5	16.5	<5	16.9
48B	-	B	<5	15.2							15	14.6	<5	15.0
49B	-	C	<5	15.1							15	14.9	<5	15.4
50B	-	B	<5	14.4							15	13.8	<5	14.6
51B	-	C	<5	15.0							10	14.3	<5	14.1
52B	-	A	<5	14.4							5	14.4	<5	15.2
53B	-	C	<5	13.5							5	13.7	<5	15.1
54B	-	C	<5	14.3							5	14.2	<5	14.5
55B	-	C	<5	15.1							10	15.4	<5	16.8
56B	-	A	<5	16.0							15	16.2	10	15.6
57B	-	C	<5	14.8							10	14.7	<5	15.4
58B	-	B	<5	14.8							15	14.7	<5	14.9
59B	-	B	<5	15.5							10	13.8	<5	15.4
60B	-	?	<5	13.6							5	11.1	--	--
61B	-	C	<5	17.3							15	15.3	5	15.6
62B	-	C	<5	15.2							5	14.1	<5	15.3
63B	-	B	<5	12.8							10	12.7	--	--

SUBJ- Subject identification code; SMOK- smoker, yes or no; COHb - (%); Hb - (g/dl).

APPENDIX H

Supporting Statistical Analysis

TABLE H-1

Comparison of Air Lead Exposures between Weapons Systems, Sections and Crews Main Effects

Effect	Statistic F	Statistic p
Weapons System	74.74	0.0001*
Field Exercise	1.68	0.1941
Section	19.02	0.0001*
Gun	14.57	0.0003*
By Weapons System		
HIPs		
Field Exercise	7.90	0.0016*
Section	7.58	0.0095*
Gun	5.40	0.0265*
M109A3's		
Field Exercise	0.24	0.7905
Section	31.56	0.0001*
Gun	10.79	0.0022*

*$\alpha = 0.05$

TABLE H-2A

Comparison of Blood Lead Parameters (PbB, FEP and Hct) Between Weapons Systems: Main Effects

Effect	HIPs		M109A3s	
	F	p	F	p
PbB				
Section	4.97	0.0033*	13.45	0.0001*
Time	53.71	0.0001*	120.09	0.0001*
FEP				
Section	1.17	0.3260	4.04	0.0092*
Time	10.78	0.0001*	6.92	0.0001*
Hematocrit				
Section	1.70	0.1748	5.12	0.0024*
Time	5.24	0.0003*	2.08	0.0740

*$\alpha = 0.05$

TABLE H2B

Comparison Between HIPs and M109A3s Across Times, for Each Blood Parameter (Medical Surveillance Subjects)

Blood Parameter	HIPs				M109A3s				F	p
	Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)		
PbB										
BL-->DPE	5.5	(4.33, 6.73)	11.9	(9.92, 14.02)	4.4	(4.00, 4.80)	12.8	(11.35, 14.26)	3.33	0.0717
BL-->IPE	5.5	(4.33, 6.73)	20.1	(17.94, 22.44)	4.4	(4.00, 4.80)	23.0	(20.41, 25.69)	6.19	0.0147*
IPE-->DPE	20.1	(17.44, 22.44)	11.9	(9.92, 14.02)	23.0	(20.41, 25.69)	12.8	(11.35, 14.26)	0.48	0.4922
FEP										
BL-->DPE	19.5	(17.58, 21.49)	19.4	(17.09, 21.89)	30.3	(22.58, 33.76)	24.1	(22.00, 26.28)	4.67	0.0337*
BL-->IPE	19.5	(17.58, 21.49)	29.8	(27.17, 32.62)	30.3	(22.58, 33.76)	31.9	(28.98, 34.96)	11.56	0.0010*
IPE-->DPE	29.8	(27.17, 32.62)	19.4	(17.09, 21.89)	31.9	(28.98, 34.96)	24.1	(22.00, 26.28)	1.47	0.2286
Hematocrit										
BL-->DPE	46.3	(45.48, 47.14)	45.4	(43.71, 47.16)	43.9	(43.10, 44.72)	45.3	(44.49, 46.07)	5.75	0.0188*
BL-->IPE	46.3	(45.48, 47.14)	44.7	(43.59, 45.75)	43.9	(43.10, 44.72)	44.6	(43.40, 45.77)	5.46	0.0217*
IPE-->DPE	44.7	(43.59, 45.75)	45.4	(43.71, 47.16)	44.6	(43.40, 45.77)	45.3	(44.49, 46.07)	0.00	0.9598

α=0.05; PbB-blood lead (μg/dl); FEP-free erythrocyte protoporphyrin (μg/dl); Hct-hematocrit (%)

TABLE H-2C

Overall Differences Among Sections, by Weapons System, at Each Time, for Each Endpoint

Endpoint	HIPs F	HIPs p	M109A3s F	M109A3s p
PbB				
BL	3.52	0.0393*	1.53	0.2343
IPE	0.89	0.4685	6.06	0.0034*
DPE	0.9	0.2508	2.93	0.0574*
FEP				
BL	0.74	0.5426	1.92	0.1551
IPE	0.79	0.5157	2.27	0.1078
DPE	0.06	0.9797	0.77	0.5223
Hematocrit				
BL	1.00	0.4198	1.68	0.1994
IPE	0.70	0.5642	4.07	0.0185*
DPE	1.46	0.2966	1.04	0.3959

*$\alpha = 0.05$

TABLE H-2D

Comparisons Among Sections, Across Times, for Each Blood Parameter and Comparisons Among Sections, Across Times, By Weapons Systems, for Each Blood Parameter

Parameter	Overall		HIPs		M109A3s	
Time	F	p	F	p	F	p
PbB						
BL-->DPE	2.01	0.1192	0.12	0.9493	1.90	0.1433
BL-->IPE	1.80	0.1532	0.53	0.6626	4.24	0.0100*
IPE-->DPE	0.06	0.9826	0.09	0.9655	0.95	0.4327
FEP						
BL-->DPE	1.63	0.1903	0.26	0.8554	1.91	0.1417
BL-->IPE	0.35	0.7875	0.21	0.8907	0.14	0.9340
IPE-->DPE	0.59	0.6258	0.21	0.8880	1.92	0.1398
Hematocrit						
BL-->DPE	1.07	0.3673	1.03	0.3976	1.69	0.1832
BL-->IPE	0.88	0.4563	0.95	0.4293	3.55	0.0214*
IPE-->DPE	0.05	0.9848	0.95	0.4327	0.87	0.4642

*$\alpha = 0.05$

TABLE H2E

Comparisons Among Sections, at Each Time, by Weapons System, for Each Blood Parameter and Comparison Between Weapons Systems, for Each Section, at Each Time, for Each Blood Parameter

Blood Parameter, Time, Section	HIPs Mean[1]	HIPs 95 Percent Asymmetrical Confidence Limits (upper, lower)	HIPs n	HIPs Scheffe[2] Grouping	M109A3s Mean	M109A3s 95 Percent Asymmetrical Confidence Limits (upper, lower)	M109A3s n	M109A3s Scheffe Grouping	F	p[3]
PbB										
BL										
1	5.6	(4.92, 6.30)	5	AB	4.7	(3.85, 5.63)	8	A	2.77	0.1245
2	3.6	(1.89, 5.92)	6	B	4.8	(4.05, 5.63)	6	A	1.78	0.2119
3	5.8	(3.33, 9.00)	5	AB	3.8	(2.93, 4.79)	7	A	4.84	0.0525
4	8.2	(3.43, 15.01)	4	A	4.3	(3.28, 5.41)	6	A	7.98	0.0223*
IPE										
1	18.9	(13.14, 25.77)	5	A	29.2	(24.62, 34.28)	8	A	11.26	0.0064*
2	18.6	(15.92, 21.51)	7	A	22.9	(17.69, 28.81)	6	A,B	3.50	0.0881
3	21.7	(13.28, 32.17)	4	A	21.5	(16.15, 27.56)	7	A,B	0.00	0.9558
4	22.9	(13.81, 34.30)	4	A	17.4	(13.94, 21.16)	6	B	3.34	0.1049
DPE										
1	12.5	(6.95, 19.66)	2	A	15.3	(12.65, 18.21)	7	A	1.73	0.2301
2	10.5	(7.55, 13.90)	6	A	13.1	(10.57, 15.96)	5	A	2.51	0.1475
3	13.4	(4.84, 26.32)	3	A	12.5	(9.17, 16.26)	7	A	0.12	0.7331
4	15.0	(----, -----)	1	A	10.1	(7.22, 13.57)	6	A	1.80	0.2376
FEP										
BL										
1	17.2	(12.06, 23.17)	5	A	31.5	(23.89, 40.10)	8	A	11.39	0.0062*
2	20.1	(14.43, 26.80)	6	A	24.4	(16.33, 34.41)	6	A	1.05	0.3297
3	19.9	(16.96, 23.16)	5	A	34.7	(28.89, 41.11)	7	A	27.07	0.0004*
4	21.0	(18.17, 23.98)	4	A	30.1	(25.07, 36.75)	6	A	9.62	0.0146*
IPE										
1	27.4	(24.42, 30.46)	5	A	34.8	(29.20, 40.93)	8	A	5.65	0.0367*
2	32.0	(26.65, 37.49)	7	A	26.0	(18.16, 35.18)	6	A	2.30	0.1573
3	28.0	(19.97, 37.49)	4	A	34.3	(28.85, 40.29)	7	A	2.93	0.1209
4	31.0	(18.41, 46.90)	4	A	31.6	(25.10, 38.75)	6	A	0.01	0.9143

TABLE H2E (Cont.)

Comparisons Among Sections, at Each Time, by Weapons System, for Each Blood Parameter and Comparison Between Weapons Systems, for Each Section, at Each Time, for Each Blood Parameter

Blood Parameter, Time, Section[4]	HIPs Mean[1]	HIPs 95 Percent Asymmetrical Confidence Limits (upper, lower)	HIPs n	HIPs Scheffe[2] Grouping	M109A3s Mean	M109A3s 95 Percent Asymmetrical Confidence Limits (upper, lower)	M109A3s n	M109A3s Scheffe Grouping	F	p[3]
DPE										
1	19.5	(5.08, 43.19)	2	A	23.8	(18.85, 29.44)	7	A	1.14	0.3212
2	19.9	(14.73, 25.79)	6	A	24.2	(21.56, 26.91)	5	A	2.65	0.1383
3	18.6	(12.84, 25.44)	3	A	22.2	(19.42, 25.15)	7	A	3.23	0.1100
4	19.0	(-----, -----)	1	A	26.6	(18.78, 35.88)	6	A	0.89	0.3892
Hematocrit										
BL										
1	46.9	(44.65, 49.18)	5	A	43.1	(41.78, 44.44)	8	A	15.51	0.0023*
2	45.5	(43.12, 47.92)	6	A	43.6	(41.58, 45.62)	6	A	2.46	0.1482
3	46.0	(44.85, 47.15)	5	A	45.3	(43.19, 47.47)	7	A	0.39	0.5451
4	47.2	(44.74, 49.75)	4	A	43.7	(41.52, 45.90)	6	A	8.07	0.0218*
IPE										
1	43.4	(39.29, 47.81)	5	A	46.4	(44.59, 48.15)	8	A	3.61	0.0841
2	44.7	(42.70, 46.76)	7	A	41.6	(37.47, 45.99)	6	B	2.99	0.1115
3	45.3	(43.36, 47.27)	4	A	44.6	(42.98, 46.31)	7	A,B	0.42	0.5323
4	45.5	(42.92, 48.13)	4	A	45.2	(43.38, 47.03)	6	A,B	0.08	0.7900
DPE										
1	45.1	(40.81, 49.71)	2	A	46.2	(43.35, 49.07)	6	A	0.25	0.6333
2	44.5	(41.39, 47.81)	6	A	44.2	(42.68, 45.68)	5	A	0.06	0.8077
3	45.8	(42.07, 49.60)	3	A	45.2	(44.01, 46.50)	7	A	0.28	0.6105
4	50.4	(-----, -----)	1	A	45.4	(43.46, 47.28)	6	A	6.26	0.0544

[1]Means and upper and lower 95 percent asymmetrical confidence limits are backtransformed.
[2]Scheffe's Multiple Comparison Procedure. Means with the same letter in each column are not different from each other.
[3]$\alpha=0.05$.
[4]HIP sections B & C; and A3 sections A & D were in the lead exposure study population.

TABLE H-3A

Blood Lead Changes at Six Time Points (Lead Study Population)
Comparison Between Weapons Systems Across Times at Each Time Increment
(Heterogeneity of Slopes)

Time Increment (Days)	Interaction Between Weapons System and Time	
	F	p
BL-->PRE1 (1-91)	0.13	0.7157
BL-->POST2 (1-98)	0.44	0.6442
BL-->IPE (1-110)	0.81	0.4921
BL-->DPE (1-181)	1.17	0.3275
PRE1-->POST1 (91-98)	0.79	0.3785
PRE1-->POST2 (91-110)	1.00	0.3720
POST1-->POST2 (98-110)	0.26	0.6161
POST2-->IPE (110-123)	0.00	0.9917

$\alpha = 0.05$

TABLE H3B

Comparison of Blood Lead Changes Over Six Time Points
(Lead Study Population)
Main Effects

Time Increment (Days)	Statistic F	p
BL-->PRE1 (1-91)		
Weapons System	0.68	0.4150
Section	2.47	0.0976
Time	168.21	0.0001*
BL-->POST1 (1-98)		
Weapons System	0.13	0.7196
Section	2.96	0.0593
Time	149.23	0.0001*
BL-->POST2 (1-110)		
Weapons System	0.10	0.7470
Section	5.62	0.0052*
Time	133.70	0.0001*
BL-->DPE (1-181)		
Weapons System	0.02	0.8990
Section	12.04	0.0001*
Time	87.38	0.0001*
PRE1-->POST1 (91-98)		
Weapons System	0.04	0.8343
Section	3.91	0.0281*
Time	14.57	0.0005*
PRE1-->POST1 (91-110)		
Weapons System	0.28	0.5963
Section	6.87	0.0020*
Time	18.08	0.0001*
POST1-->POST2 (98-110)		
Weapons System	1.33	0.2563
Section	3.29	0.0475*
Time	4.40	0.0423*
POST2-->IPE (110-123)		
Weapons System	3.03	0.0897
Section	9.51	0.0004*
Time	2.34	0.1336

*$\alpha = 0.05$

TABLE H-3C

Comparison of Blood Lead Changes Over Six Time Points (Lead Study Population) Effects By Weapons System

Time Increment (Days)	HIPs F	HIPs p	M109A3s F	M109A3s p
BL-->PRE1 (1-91)				
Section	0.00	0.9879	7.53	0.0125*
Time	70.30	0.0001*	126.62	0.0001*
BL-->POST1 (1-98)				
Section	0.20	0.6623	10.37	0.0031*
Time	46.89	0.0001*	149.64	0.0001*
BL-->POST2 (1-110)				
Section	0.49	0.4901	14.79	0.0004*
Time	44.03	0.0001*	107.55	0.0001*
BL-->DPE (1-181)				
Section	0.00	0.9660	34.31	0.0001*
Time	27.95	0.0001*	74.86	0.0001*
PRE1-->POST1 (91-98)				
Section	0.12	0.7323	11.88	0.0026*
Time	2.75	0.1143	17.96	0.0004*
PRE1-->POST2 (91-110)				
Section	0.42	0.5238	15.87	0.0004*
Time	3.88	0.0329*	17.32	0.0001*
POST1-->POST2 (98-110)				
Section	0.80	0.3822	7.41	0.0131*
Time	0.91	0.3517	4.77	0.0131*
POST2-->IPE (110-123)				
Section	0.29	0.5940	18.17	0.0004*
Time	0.99	0.3329	1.21	0.3853

*$\alpha = 0.05$

TABLE H3D

Blood Lead Observed and Estimated Means with Estimated 95% Asymmetrical Confidence Limits at Each Day for Pooled Weapons Systems Crew and for Each Weapons System for Each Time Increment (Lead Exposure Study Subjects-6 Time Points)

Time (Days)	Pooled Units			HIPs			M109A3s		
	Observed Mean	Estimated Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	Observed Mean	Est. Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	Observed Mean	Est. Mean	95 Percent Asymmetrical Confidence Limits (upper, lower)
BL-->PRE1									
1	4.6	4.5	(3.14, 6.22)	4.8	4.3	(2.56, 6.59)	4.3	4.3	(3.06, 5.74)
91	15.4	15.8	(13.07, 18.81)	16.0	16.2	(12.54, 20.33)	14.9	17.9	(15.31, 20.78)
Time effect			F=168.21, p=0.0001*			F=70.30, p=0.0001*			F=126.62, p=0.0001*
BL-->POST1									
1	4.6	4.3	(3.03, 5.91)	4.8	4.3	(2.40, 6.86)	4.3	4.3	(3.15, 5.62)
91	15.4	15.4	(12.84, 18.26)	16.0	16.2	(12.18, 20.80)	14.9	17.9	(15.50, 20.55)
98	20.2	19.1	(16.17, 22.19)	19.9	18.2	(13.96, 23.10)	20.5	21.8	(19.08, 24.63)
Time effect			F=149.32, p=0.0001*			F=46.89, p=0.0001*			F=149.64, p=0.0001*
BL-->POST2									
1	4.6	4.3	(2.99, 5.80)	4.8	4.3	(2.46, 6.76)	4.3	4.3	(2.98, 5.86)
91	15.4	15.3	(12.76, 18.08)	16.0	16.2	(12.32, 20.62)	14.9	17.9	(15.12, 21.01)
98	20.2	18.9	(16.08, 22.99)	19.9	18.2	(14.10, 22.92)	20.5	21.8	(18.65, 25.13)
110	23.4	21.2	(18.14, 24.40)	22.0	20.7	(16.28, 25.67)	24.7	27.9	(24.40, 31.74)
Time effect			F=133.70, p=0.0001*			F=44.03, p=0.0001*			F=107.55, p=0.0001*
PRE1-->POST1									
91	15.4	15.4	(12.53, 18.66)	16.0	16.2	(12.03, 21.00)	14.9	17.9	(15.13, 21.00)
98	20.2	19.1	(15.81, 22.63)	19.9	18.2	(13.80, 23.31)	20.5	21.8	(18.66, 25.11)
Time effect			F=14.57, p=0.0005*			F=2.75, p=0.1143			F=17.96, p=0.0004*

TABLE H3D (Cont.)

Blood Lead Observed and Estimated Means with Estimated 95% Asymetrical Confidence Limits at Each Day for Pooled Weapons Systems Crew and for Each Weapons System for Each Time Increment (Lead Exposure Study Subjects-6 Time Points)

Time (Days)	Pooled Units			HIPs			M109A3s		
	Observed Mean	Estimated Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	Observed Mean	Est. Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	Observed Mean	Est. Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)
PRE1-->POST2									
91	15.4	15.3	(12.54, 18.26)	16.0	16.2	(12.26, 20.69)	14.9	17.9	(14.79, 21.40)
98	20.2	18.9	(15.83, 22.19)	19.9	18.2	(14.04, 22.99)	20.5	21.8	(18.28, 25.57)
110	23.4	21.2	(17.88, 24.61)	22.0	20.7	(16.22, 25.75)	24.7	27.9	(23.97, 32.23)
Time effect			F=18.08, p=0.0001*			F=3.88, p=0.0329*			F=17.32, p=0.0001*
POST1-->POST2									
98	20.2	18.4	(15.02, 22.06)	19.9	18.2	(13.63, 23.54)	20.5	21.8	(18.27, 25.57)
110	23.4	20.6	(17.02, 24.47)	22.0	20.7	(15.77, 26.32)	24.7	27.9	(23.97, 32.24)
Time effect			F=4.40, p=0.0423*			F=0.91, p=0.3517			F=4.77, p=0.0411*
POST2-->IPE									
110	23.4	21.2	(17.74, 24.89)	22.0	20.7	(16.56, 25.32)	24.7	27.9	(23.53, 32.74)
123	21.3	19.1	(15.88, 22.68)	19.9	19.5	(15.5, 24.06)	24.9	27.3	(22.95, 32.06)
Time effect			F=2.34, p=0.1336			F=0.99, p=0.3329			F=1.21, p=0.2853
BL-->DPE									
1	4.6	4.5	(3.21, 6.02)	4.8	4.3	(2.45, 6.76)	4.3	4.3	(2.99, 5.85)
91	15.4	15.7	(13.21, 18.46)	16.0	16.2	(12.31, 20.63)	14.9	17.9	(15.14, 20.99)
98	20.2	19.4	(16.58, 22.41)	19.9	18.2	(14.09, 22.93)	20.5	21.8	(18.67, 25.11)
110	23.4	21.7	(18.68, 24.85)	22.0	20.7	(16.27, 25.68)	24.7	27.9	(24.44, 31.72)
123	21.3	19.6	(16.78, 22.64)	19.9	19.6	(15.26, 24.41)	22.5	27.3	(23.83, 31.04)
181	13.4	14.4	(11.76, 17.24)	14.9	16.5	(12.15, 21.55)	12.2	14.3	(11.61, 17.34)
Time effect			F=87.38, p=0.0001*			F=27.95, p=0.0001*			F=74.86, p=0.0001*

*α = 0.05; PbB-blood lead ($\mu g/dl$)

TABLE H3E

Blood Lead Observed and Estimated Means with Estimated 95% Asymmetrical Confidence Limits for HIP Section Crews, at Each Time Increment for Each Time Point (Lead Exposure Study Subjects-6 Time Points)

Time (Days)	Section B Observed Mean	Section B Estimated Mean	Section B 95 Percent Asymmetrical Confidence Limits (lower, upper)	Section C Observed Mean	Section C Estimated Mean	Section C 95 Percent Asymmetrical Confidence Limits (lower, upper)
BL-->PRE1						
1	4.4	4.3	(2.79, 6.24)	5.2	4.7	(2.69, 7.37)
91	16.4	16.2	(13.04, 19.70)	15.7	15.5	(11.56, 20.04)
Time Effect			F=58.62, p=0.0001*			F=26.58, p=0.0004*
BL-->POST1						
1	4.4	4.3	(2.30, 7.03)	5.2	4.7	(2.79, 7.21)
91	16.4	16.2	(11.96, 21.09)	15.7	15.5	(11.76, 19.77)
98	18.8	18.2	(13.72, 23.41)	20.8	20.6	(16.21, 25.43)
Time Effect			F=21.21, p=0.0001*			F=26.41, p=0.0001*
BL-->POST2						
1	4.4	4.3	(2.50, 6.69)	5.2	4.7	(2.79, 7.21)
91	16.4	16.2	(12.40, 20.51)	15.7	15.5	(11.76, 19.77)
98	18.8	18.2	(14.19, 22.80)	20.8	20.6	(16.21, 25.43)
110	20.8	20.7	(16.38, 25.55)	23.0	22.7	(18.08, 27.76)
Time Effect			F=22.21, p=0.0001*			F=23.04, p=0.0001*
PRE1->POST1						
91	16.4	16.2	(11.00, 22.40)	15.7	15.5	(12.10, 19.35)
98	18.8	18.2	(12.70, 24.79)	20.8	20.6	(16.60, 24.95)
Time Effect			F=0.32, p=0.5861			F=4.17, p=0.0685

TABLE H3E (Cont.)

Blood Lead Observed and Estimated Means with Estimated 95% Assymetrical Confidence Limits for HIP Section Crews, at Each Time Increment for Each Time Point (Lead Exposure Study Subjects-6 Time Points)

Time (Days)	Section B			Section C		
	Observed Mean	Estimated Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)	Observed Mean	Estimated Mean	95 Percent Asymmetrical Confidence Limits (lower, upper)
PRE1-->POST2						
91	16.4	16.2	(11.88, 21.19)	15.7	15.5	(11.96, 19.52)
98	18.8	18.2	(13.64, 23.52)	20.8	20.6	(16.44, 25.14)
110	20.8	20.7	(15.78, 26.31)	23.0	22.7	(18.32, 27.47)
Time effect			F=0.98, p=0.4029			F=3.56, p= 0.0543
POST1-->POST2						
98	18.8	18.2	(13.07, 24.28)	20.8	20.6	(15.96, 25.83)
110	20.8	20.7	(15.17, 27.11)	23.0	22.7	(17.75, 28.18)
Time effect			F=0.48, p=0.5071			F=0.42, p=0.5299
POST2-->IPE						
110	20.8	20.7	(18.21, 23,37)	23.0	22.7	(17.45, 28.56)
123	19.6	19.6	(17.14, 22.16)	19.8	19.8	(14.96, 25.35)
Time effect			F=0.53, p=0.4869			F=0.70, p=0.4228
BL-->DPE						
1	4.4	4.3	(2.65, 6.45)	5.2	4.7	(2.71, 7.33)
91	16.4	16.2	(12.73, 20.09)	15.7	15.5	(11.62, 19.96)
98	18.8	18.2	(14.55, 22.35)	20.8	20.6	(16.04, 25.65)
110	20.8	20.7	(16.76, 25.07)	23.0	22.7	(17.90, 27.99)
123	19.6	19.6	(15.74, 23.82)	19.8	19.8	(15.38, 24.81)
181	16.8	16.5	(12.63, 20.93)	13.4	12.9	(9.08, 17.42)
Time effect			F=17.13, p=0.0001*			F=13.40, p=0.0001*

α=0.05; PbB-blood lead (μg/dl)

TABLE H3F

Blood Lead Observed and Estimated Means with Estimated 95% Asymmetrical Confidence Limits for M109A3 Section Crews, at Each Time Increment for Each Time Point (Lead Exposure Study Subjects-6 Time Points)

Time (Days)	Section A Observed Mean	Section A Estimated Mean	Section A 95 Percent Asymmetrical Confidence Limits (lower, upper)	Section D Observed Mean	Section D Estimated Mean	Section D 95 Percent Asymmetrical Confidence Limits (lower, upper)
BL-->PRE1						
1	4.3	4.3	(2.94, 5.91)	4.3	4.3	(3.02, 5.77)
91	18.2	17.9	(15.04, 21.10)	11.7	11.5	(9.36, 13.85)
Time effect			F=90.84, p=0.0001*			F=39.34, p=0.0001*
BL-->POST1						
1	4.3	4.3	(3.10, 5.69)	4.3	4.3	(3.10, 5.65)
91	18.2	17.9	(15.40, 20.68)	11.7	11.5	(9.50, 13.68)
98	21.8	21.8	(18.96, 24.78)	19.2	19.1	(16.48, 21.86)
Time effect			F=90.09, p=0.0001*			F=63.54, p=0.0001*
BL-->POST2						
1	4.3	4.3	(3.00, 5.84)	4.3	4.3	(2.88, 5.97)
91	18.2	17.9	(15.16, 20.96)	11.7	11.5	(9.10, 14.17)
98	21.8	21.8	(18.69, 25.08)	19.2	19.1	(15.95, 22.48)
110	28.2	27.9	(24.45, 31.69)	21.2	20.8	(17.56, 24.39)
Time effect			F=72.39, p=0.0001*			F=40.51, p=0.0001*
PRE1-->POST1						
91	18.2	17.9	(14.89, 21.28)	11.7	11.5	(9.17, 14.08)
98	21.8	21.8	(18.39, 25.43)	19.2	19.1	(16.04, 22.37)
Time effect			F=3.22, p=0.1031			F=18.09, p=0.0017*

TABLE H3F (Cont.)

Blood Lead Observed and Estimated Means with Estimated 95% Asymmetrical Confidence Limits for M109A3 Section Crews, at Each Time Increment for Each Time Point (Lead Exposure Study Subjects-6 Time Points)

Time (Days)	Section A Observed Mean	Section A Estimated Mean	Section A 95 Percent Asymmetrical Confidence Limits (lower, upper)	Section D Observed Mean	Section D Estimated Mean	Section D 95 Percent Asymmetrical Confidence Limits (lower, upper)
PRE1-->POST2						
91	18.2	17.9	(14.79, 21.41)	11.7	11.5	(8.80, 14.55)
98	21.8	21.8	(18.28, 25.57)	19.2	19.1	(15.55, 22.95)
110	28.2	27.9	(23.97, 32.23)	21.2	20.8	(17.15, 24.89)
Time effect			F=8.30, p=0.0037*			F=10.01, p=0.0017*
POST1-->POST2						
98	21.8	21.8	(18.42, 25.40)	19.2	19.1	(15.29, 23.28)
110	28.2	27.9	(24.14, 32.04)	21.2	20.8	(16.87, 25.22)
Time effect			F=6.85, p=0.0257*			F=0.46, p=0.5118
POST2-->IPE						
110	28.2	27.9	(23.42, 32.88)	21.2	20.8	(16.66, 25.49)
123	27.5	27.3	(22.84, 32.19	17.5	17.4	(13.56, 21.62)
Time Effect			F=0.05, p=0.8358			F=1.69, p=0.2232
BL-->DPE						
1	4.3	4.3	(3.02, 5.81)	4.3	4.3	(2.90, 5.94)
91	18.2	17.9	(15.21, 20.90)	11.7	11.5	(9.14, 14.12)
98	21.8	21.8	(18.75, 25.02)	19.2	19.1	(16.00, 22.42)
110	28.2	27.9	(24.51, 31.62)	21.2	20.8	(17.62, 24.33)
123	27.5	27.3	(23.91, 30.94)	17.5	17.4	(14.43, 20.56)
181	14.4	14.3	(11.68, 17.25)	10.3	10.1	(7.94, 12.62)
Time effect			F=52.69, p=0.0001*			F=27.11, p=0.0001*

*α = 0.05; PbB-blood lead (μg/dl)

TABLE H-4A

Main Effects and Effects By Weapons System; Correlation of Number of Rounds Fired With TWA

Effect	Statistic	
	F	p
Overall		
Weapons System	83.79	0.0001*
Exercise	1.15	0.3221
Rounds	33.59	0.0001*
By Weapons System		
HIPs		
Exercise	2.99	0.0638
Rounds	1.39	0.2470
A3s		
Exercise	0.80	0.4559
Rounds	32.75	0.0001*

*$\alpha = 0.05$

TABLE H-4B

Relationship Between Rounds and Time Weighted Average for Each Weapons System and for Each Weapons System, By Exercise Fit to the Model

Weapons System Exercise	Statistic				
	F	p	R^2	r	CV
Weapons System					
HIPs	6.31	0.0166*	0.1492	0.3863	50.20
A3s	31.49	0.0001*	0.4344	0.6591	27.95
Weapons System; Exercise					
HIPs					
Exer 1	56.55	0.0001*	0.8372	0.9150	20.60
Exer 2	1.38	0.2646	0.1116	0.3341	35.98
Exer 3	6.67	0.0273*	0.4402	0.6326	45.48
A3s					
Exer 1	0.90	0.3592	0.0603	0.2456	30.81
Exer 2	10.52	0.0088*	0.5128	0.7161	29.42
Exer 3	55.37	0.0001*	0.8099	0.8999	18.92

*$\alpha = 0.05$

The regression equations for the regression of TWA on rounds for each weapons system and for each weapons system, for each field exercise are as follows:

HIPs: $y = -0.551774468 + 1.162577658x$

A3s: $y = 0.491266898 + 2.412890771x$

HIPs (Exer 1) $y = -85.84449127 + 6.42325397x$

(Exer 2) $y = 24.64923412 - 0.50265058x$

(Exer 3) $y = -20.62528085 + 2.39115436x$

A3s (Exer 1) $y = 19.40613490 + 1.08793255x$

(Exer 2) $y = 3.618333333 + 2.16000000x$

(Exer 3) $y = -23.75826227 + 3.93402530x$

TABLE H-5A

Relationship Between Mean 8-Hr Time Weighted Average and Change in Blood Lead Levels (DPbB) Fit to the Model

Model	Statistic			
	F	p	R^2	CV
Overall	12.07	0.0001*	0.4014	43.10
By Weapons System				
HIPs	3.83	0.0183*	0.2525	48.41
A3s	0.13	0.9400	0.0112	38.67
By Weapons System; By Field Exercise				
HIPs				
Field Exercise I	0.00	0.9651	0.0002	51.05
Field Exercise II	1.47	0.2503	0.1181	35.85
Field Exercise III	0.06	0.8181	0.0055	58.26
A3s				
Field Exercise I	1.57	0.2321	0.1078	29.31
Field Exercise II	1.11	0.3191	0.1100	42.26
Field Exercise III	0.84	0.3780	0.0712	43.48

*$\alpha = 0.05$

TABLE H-5B

Relationship Between Mean 8-Hr Time Weighted Average and Change in Blood Lead Levels (ΔPbB)
Main Effects

Effect	Statistic	
	F	p
Overall		
Weapons System	42.68	0.0001*
Exercise	0.90	0.4101
Change in PbB	0.43	0.5131
By Weapons System		
HIPs		
Exercise	4.27	0.0222*
Change in PbB	0.26	0.6134
A3s		
Exercise	0.07	0.9325
Change in PbB	0.40	0.5331
By Weapons System; By Field Exercise		
HIPs		
Field Exercise I	0.00	0.9651
Field Exercise II	1.47	0.2503
Field Exercise III	0.06	0.8181
A3s		
Field Exercise I	1.57	0.2321
Field Exercise II	1.11	0.3191
Field Exercise III	0.84	0.3780

*$\alpha = 0.05$

TABLE H-6A

Correlation Between Maximum Blood Lead Levels and Mean 8-Hr TWA

Model	F	p	R^2	CV
By Weapons System				
HIPs	3.73	0.0202*	0.2477	48.57
M109A3s	4.98	0.0054*	0.2934	32.31
By Field Exercise				
HIPs				
Field Exercise I	0.12	0.7350	0.0108	50.77
Field Exercise II	1.37	0.2660	0.1110	35.99
Field Exercise III	0.03	0.8775	0.0025	58.35
M109A3s				
Field Exercise I	0.04	0.8441	0.0031	30.98
Field Exercise II	5.34	0.0461*	0.3725	35.49
Field Exercise III	13.65	0.0031*	0.5321	29.56

*$\alpha = 0.05$

TABLE H-6B

Relationship Between Maximum (Peak) Blood Lead Levels and Mean 8-Hr Time Weighted Average Main Effects

Effect	Statistic F	Statistic p
Overall		
Weapons System	40.97	0.0001*
Field Exercise	2.56	0.0841
MaxPbB	9.53	0.0029*
By Weapons System		
HIPs		
Field Exercise	5.55	0.0082*
MaxPbB	0.04	0.8376
A3s		
Field Exercise	1.24	0.3007
MaxPbB	14.91	0.0005*
By Weapons System; By Field Exercise		
HIPs		
Field Exercise I	0.12	0.7350
Field Exercise II	1.37	0.2660
Field Exercise III	0.03	0.8775
A3s		
Field Exercise I	0.04	0.8441
Field Exercise II	5.34	0.0461*
Field Exercise III	13.65	0.0031*

*$\alpha = 0.05$

Regression Equations: (MaxPbB)

A3s; Exercise II: $y = -8.052241060 + 1.619805795x$

Exercise III: $y = 3.490184975 + 1.436691123x$

TABLE H-7A

Correlation of Blood Lead with Free Erythrocyte Protoporphyrin
Fit to the Model

	F	p*	R^2	CV
Overall	12.83	0.0001*	0.2029	7.63
By Weapons system				
HIPs	18.62	0.0001*	0.2512	7.60
A3s	3.66	0.0281*	0.0494	7.66
By Weapons System; By Population				
<u>HIPs</u>				
Lead Study	7.86	0.0008*	0.1714	7.82
Medical Surv.	15.62	0.0001*	0.4940	6.83
<u>A3s</u>				
Lead Study	0.99	0.3740	0.0207	7.39
Medical Surv.	2.55	0.0893	0.1040	8.26

Regression Equation for the HIP Medical Surveillance Population:
$\text{Log}_{10}\ \text{FEP} = 1.196530420 + 0.012341831\text{PbB(mean)}$

*$\alpha = 0.05$

TABLE H-7B

Correlation of Blood Lead and Free Erythrocyte Protoporphyrin
Main Effects

Effect	F	p
Weapons System	32.08	0.0001*
Population	0.79	0.3739
Blood Lead	33.70	0.0001*
Day	7.38	0.0071*
Interaction (PbB*Weapons System)	17.33	0.0001*

*$\alpha = 0.05$

TABLE H-7C

Correlation of Blood Lead with Free Erythrocyte Protoporphyrin Effects By Weapons system

	Weapons System			
	HIPs		A3s	
Effects	F	p	F	p
Population	3.16	0.0783	0.73	0.3934
Blood Lead	39.05	0.0001*	3.34	0.0696
Day	2.63	0.1075	6.06	0.0151*
Interaction (PbB*Pop)	4.10	0.0454*	0.05	0.8157

*$\alpha = 0.05$

TABLE H-7D

Correlation of Blood Lead and Free Erythrocyte Protoporphyrin Effects by Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Blood Lead	35.03	0.0001*	4.09	0.0449*
Day	1.59	0.2101	6.38	0.0126*

*$\alpha = 0.05$

TABLE H-7E

Free Erythrocyte Protoporphyrin (mg/dl)
Geometric Means and Associated 95% Confidence Limits;
By Weapons System

	Weapons System	
	HIPs	A3s
Day	Mean (Lower, Upper) n	Mean (Lower, Upper) n
1	19.89 (17.61, 22.46) 21	29.73 (26.72, 32.74) 33
90	23.24 (20.84, 25.92) 14	22.78 (20.53, 25.29) 17
98	26.03 (22.85, 29.65) 14	29.00 (25.67, 32.77) 17
110	28.04 (24.61, 31.94) 14	30.44 (27.43, 33.77) 15
123	30.13 (27.86, 32.58) 30	31.09 (28.61, 33.79) 33
181	19.51 (18.03, 21.14) 21	25.10 (22.93, 27.46) 31

TABLE H-7F

Free Erythrocyte Protoporphyrin
Geometric Means and Associated 95% Confidence Limits;
By Weapons System; By Population (mg/dl)

	HIPs							
	Lead Study Population				Medical Surv. Population			
Day	Mean	(Lower,	Upper)	n	Mean	(Lower,	Upper)	n
1	19.81	(16.89,	23.23)	11	19.99	(15.81,	25.27)	10
90	23.24	(20.84,	25.92)	14	***	***	***	**
98	26.03	(22.85,	29.65)	14	***	***	***	**
110	28.04	(24.61,	31.94)	14	***	***	***	**
123	30.83	(27.17,	34.98)	14	29.53	(26.45,	32.96)	16
181	19.14	(16.85,	21.75)	12	20.03	(17.99,	22.31)	9
	A3s							
1	31.78	(28.25,	35.75)	15	27.94	(23.48,	33.23)	16
90	22.78	(20.53,	25.29)	17	***	***	***	**
98	29.00	(25.67,	32.77)	17	***	***	***	**
110	30.44	(27.43,	33.77)	15	***	***	***	**
123	32.16	(28.91,	35.78)	17	29.99	(26.07,	34.50)	16
181	27.65	(23.83,	32.08)	16	22.63	(20.79,	24.64)	15

TABLE H-7G

Correlation Between PbB and FEP with Day 181 (DPE) Removed
Fit to the Model

Model	F	p	R^2	CV
Overall	7.86	0.0001*	0.1643	7.58
By Weapons System				
HIPs	20.38	0.0001*	0.3117	7.08
A3s	0.98	0.3795	0.0175	7.63
By Weapons System, By Population				
HIPs				
Lead Study	12.79	0.0001*	0.2856	6.86
Medical Survey	10.65	0.0005*	0.4809	7.25
A3s				
Lead Study	2.10	0.1290	0.0512	7.11
Medical Surv.	0.28	0.7570	0.0190	8.93

*$\alpha = 0.05$

TABLE H-7H

Correlation of PbB with FEP with Day 181 (DPE) Deleted
Main Effects

Effect	F	p
Weapons System	20.87	0.0001*
Population	0.32	0.5741
Blood Lead	2.10	0.1493
Day	1.95	0.1641
Interaction(PbB*Weapons System)	10.68	0.0013*

*$\alpha = 0.05$

TABLE H-7I

Correlation of PbB with FEP with Day 181 (DPE) Deleted Effects by Weapons System

	Weapons System			
	HIPs		A3s	
	F	p	F	p
Population	0.62	0.4322	0.02	0.8876
Blood Lead	0.51	0.4761	1.88	0.1732
Day	9.57	0.0026*	1.17	0.2814
Interaction (PbB* Population)	1.35	0.2491	0.02	0.8965

*$\alpha = 0.05$

TABLE H-7J

Correlation of PbB with FEP with Day 181 Deleted Effects by Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Blood Lead	0.06	0.8136	1.94	0.1668
Day	12.31	0.0007*	1.20	0.2765

*$\alpha = 0.05$

TABLE H-7K

Correlation of PbB with FEP with Day 181 Deleted
Effects by Weapons System; By Population

	Weapons System			
	HIPs		A3s	
Effects	F	p	F	p
Lead Study Population				
Blood Lead	0.89	0.3482	3.89	0.0520
Day	14.25	0.0004*	3.62	0.0607
Medical Surveillance Population				
Blood Lead	4.26	0.0505	0.12	0.7360
Day	0.08	0.7775	0.36	0.5525

*$\alpha = 0.05$

TABLE H-8A

Correlation of PbB with Hb
Fit to the Model

Model	F	p	R^2	CV
Overall				
Complete	1.15	0.3325	0.0180	6.45
With interaction	1.33	0.2524	0.0258	6.43
By Weapons System				
HIPs	3.91	0.0108*	0.0962	5.79
A3s	0.48	0.6999	0.0102	6.84
By Weapons System, By Population				
HIPs				
Lead Study	3.29	0.0735	0.0410	5.77
Medical Surv.	1.30	0.2626	0.0379	5.84
A3s				
Lead Study	0.00	0.9666	0.0000	6.76
Medical Surv.	0.97	0.3312	0.0215	7.02

*$\alpha = 0.05$

TABLE H-8B

Correlation of PbB with Hb
Main Effects

Effect	F	p
Weapons System	2.58	0.1097
Population	0.90	0.3430
Blood Lead	3.81	0.0521
Day	0.19	0.6605
Interaction (Weapons System*PbB)	2.02	0.1569

$\alpha = 0.05$

TABLE H-8C

Correlation of PbB with Hb
Effects by Weapons System

Effect	Weapons System: HIPs F	HIPs p	A3s F	A3s p
Population	5.87	0.0170*	0.38	0.5396
Blood Lead	2.87	0.0930	0.90	0.3444
Day	0.27	0.6042	0.80	0.3720

*$\alpha = 0.05$

TABLE H-8D

Correlation of PbB with Hb
Effects by Weapons System; by Population

Effect	F	p
HIPs		
Lead Study: PbB	3.29	0.0735
Medical Surv.: PbB	1.30	0.2626
A3s		
Lead Study: PbB	0.00	0.9666
Medical Survey: PbB	0.97	0.3312

$\alpha = 0.05$

TABLE H-8E

Correlation of PbB with Hb (g/dl)
Hemoglobin Means; by Weapons System

	Weapons System					
	HIPs			A3s		
Day	Mean[1]	+/-SE[2]	n	Mean	+/-SE	n
1	15.49	0.150	22	14.84	0.160	31
90	14.76	0.205	14	14.98	0.263	17
98	18.24	0.208	14	14.59	0.196	17
110	14.28	0.179	14	14.57	0.242	15
123	14.97	0.164	30	14.63	0.177	33
181	15.16	0.187	22	15.08	0.215	30

[1] arithmetic mean
[2] standard error of the mean

TABLE H-8F

Correlation of PbB with Hb (g/dl)
Hemoglobin Means; by Weapons System; By Population

	HIPs					
	Lead Study Population			Medical Survey Population		
Day	Mean[1]	+/-SE[2]	n	Mean[1]	+/-SE[2]	n
1	15.38	0.219	12	15.62	0.024	10
90	14.76	0.205	14	****	****	**
98	14.24	0.208	14	****	****	**
110	14.28	0.179	14	****	****	**
123	15.06	0.256	14	14.90	0.216	16
181	15.03	0.229	12	15.31	0.313	10
	A3s					
1	14.87	0.187	15	14.81	0.262	16
90	14.98	0.263	17	****	****	**
98	14.59	0.196	17	****	****	**
110	14.57	0.241	15	****	****	**
123	14.99	0.180	17	14.26	0.286	16
181	14.98	0.380	16	14.21	0.169	14

[1] arithmetic mean
[2] standard error of the mean

TABLE H-8G

Correlation Between Blood Lead and Hemoglobin with Day 181 (DPE) Removed Fit to the Model

Model	F	p	R^2	CV
Overall				
Complete	2.43	0.0490*	0.0461	6.15
With Interaction	2.39	0.0390*	0.0565	6.13
By Weapons System				
HIPs	5.16	0.0025*	0.1482	5.62
A3s	1.65	0.1823	0.0434	6.38
By Weapons System, By Population				
HIPs				
Lead Study				
Complete	2.21	0.1176	0.0647	5.82
Reduced	3.04	0.0858	0.0447	5.84
Medical Surv.				
Complete	3.02	0.0683	0.2081	5.21
Reduced	1.92	0.1788	0.0740	5.52
A3s				
Lead Study				
Complete	0.38	0.6855	0.0096	5.92
Reduced	0.11	0.7466	0.0013	5.91
Medical Surv.				
Complete	1.42	0.2581	0.0892	7.57
Reduced	0.76	0.3903	0.0247	7.70

*$\alpha = 0.05$

TABLE H-8H

Correlation between PbB and Hb with Day 181 (DPE) Removed
Main Effects

Effect	F	p
Weapons System	1.21	0.0709
Population	0.00	0.9687
Blood Lead	1.57	0.2123
Day	6.54	0.0113*

*α = 0.05

TABLE H-8I

Correlation Between PbB and Hb with Day 181 Removed
Effects by Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Population	4.48	0.0371*	2.92	0.0902
Blood Lead	0.12	0.7337	1.40	0.2398
Day	4.20	0.0434*	2.88	0.0926

*α = 0.05

TABLE H-8J

Correlation Between PbB and Hb with Day 181 Removed
Effects by Weapons System; By Population

	Weapons System			
	HIPs		A3s	
Effect	F	p*	F	p*
Lead Study				
Blood Lead	0.02	0.8906	0.70	0.4046
Day	1.37	0.2468	0.65	0.4215
Medical Surv.				
Blood Lead	0.94	0.3412	0.80	0.3795
Day	3.90	0.0605	2.05	0.1626

*$\alpha = 0.05$

TABLE H-9A

Correlation Between Blood Lead and Hematocrit
Fit to the Model

Effect	F	p	R^2	CV
Overall	2.83	0.0165*	0.0532	7.10
By Weapons System				
HIPs	4.02	0.0093*	0.0988	8.34
A3s	0.75	0.5243	0.0158	5.89
By Weapons System, By Population				
<u>HIPs</u>				
Lead Study	2.44	0.0938	0.0604	9.43
Medical Surv.	0.50	0.6128	0.0301	5.41
<u>A3s</u>				
Lead Study	1.66	0.1949	0.0342	5.82
Medical Surv.	0.13	0.8807	0.0058	6.09

*$\alpha = 0.05$

TABLE H-9B

Correlation of Blood Lead with Hematocrit
Main Effects

Effect	F	p
Weapons System	6.13	0.0140*
Population	4.04	0.0455*
Blood Lead	3.55	0.0606
Day	0.42	0.5185
Interaction (Blood Lead*Weapons System)	8.17	0.0046*

*$\alpha = 0.05$

TABLE H-9C

Correlation Between Blood Lead and Hematocrit Effects by Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Population	5.53	0.0205*	0.10	0.7577
Blood Lead	4.07	0.0461*	0.06	0.8125
Day	0.02	0.8886	1.40	0.2387

*$\alpha = 0.05$

TABLE H-9D

Correlation Between Blood Lead and Hematocrit Effects by Weapons System; By Population

	Weapons System			
	HIPs		A3s	
Effects	F	p	F	p
Medical Surveillance				
Blood Lead	0.03	0.8535	0.39	0.7224
Day	0.50	0.4831	0.24	0.6231
Lead Study				
Blood Lead	4.14	0.0453*	0.39	0.5356
Day	0.00	0.9822	1.79	0.1838

*$\alpha = 0.05$

TABLE H-9E

Correlation Between Blood Lead and Hematocrit
Hematocrit Means by Weapons System

	Weapons System					
	HIPs			A3s		
Day	Mean[1]	+/-SE[2]	n	Mean	+/-SE	n
1	46.28	0.384	21	44.25	0.382	31
90	45.00	0.589	14	45.14	0.649	17
98	42.76	0.515	14	43.59	0.555	17
110	45.54	0.485	14	43.78	0.584	15
123	43.99	1.143	30	45.00	0.506	33
181	45.57	0.555	21	45.22	0.521	31

[1] arithmetic mean
[2] standard error of the mean

TABLE H-9F

Correlation Between Blood Lead and Hematocrit (%)
Hematocrit Means by Weapons System; By Population

	HIPs					
	Lead Study Population			Medical Survey Population		
Day	Mean[1]	+/-SE[2]	n	Mean	+/-SE	n
1	45.76	0.534	11	46.85	0.522	10
90	45.00	0.589	14	****	****	**
98	42.76	0.515	14	****	****	**
110	42.54	0.485	14	****	****	**
123	42.87	2.363	14	44.96	0.604	16
181	45.02	0.642	12	46.30	0.962	9
	A3s					
1	43.73	0.493	15	44.73	0.567	16
90	45.14	0.649	17	****	****	**
98	43.59	0.555	17	****	****	**
110	43.78	0.584	15	****	****	**
123	45.92	0.469	17	44.03	0.869	16
181	45.10	0.903	16	45.35	0.519	15

[1] arithmetic mean
[2] standard error of the mean

TABLE H-9G

Correlation Between PbB and Hct with Day 181 (DPE) Removed
Fit to the Model

Model	F	p	R^2	CV
Overall	2.69	0.0222*	0.0631	7.30
By Weapons System				
HIPs	3.66	0.0154*	0.1097	8.82
A3s	0.58	0.6277	0.0158	5.72
By Weapons System, By Population				
HIPs				
Lead Study	2.29	0.1097	0.0667	10.01
Medical Surv.	4.55	0.0216*	0.2836	4.47
A3s				
Lead Study	1.62	0.2052	0.0398	5.31
Medical Surv.	0.81	0.4561	0.0527	6.59

$^*\alpha = 0.05$

TABLE H-9H

Correlation Between PbB and Hct with Day 181 (DPE) Removed
Main Effects

Effect	F	p
Weapons System	5.73	0.0176*
Population	2.05	0.1534
Blood Lead	0.00	0.9782
Day	1.28	0.2585
Interaction (Weapons System*PbB)	7.77	0.0058*

$^*\alpha = 0.05$

TABLE H-9I

Correlation Between PbB and Hct with Day 181 Removed
Effects by Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Population	3.61	0.0607	0.01	0.9102
Blood Lead	0.17	0.6811	1.35	0.2475
Day	1.18	0.2807	0.41	0.5250

$\alpha = 0.05$

TABLE H-9J

Correlation Between PbB and Hct with Day 181 Removed
Effects By Weapons System; By Population

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Lead Study				
Blood Lead	0.72	0.3996	0.50	0.4816
Day	0.27	0.6027	0.20	0.6534
Medical Surveillance				
Blood Lead	3.85	0.0620	1.16	0.2913
Day	8.11	0.0091*	1.60	0.2165

*$\alpha = 0.05$

TABLE H-10A

Correlation Between Carboxyhemoglobin and Free Erythrocyte Protoporphyrin
Fit to the Model

Model	F	p	R^2	CV
Overall	14.13	0.0001*	0.2197	7.56
By Weapons System				
HIPs	22.52	0.0001*	0.2886	7.41
A3s	3.48	0.0335*	0.0474	7.68
By Weapons System, By Population				
HIPs				
Lead Study	26.56	0.0001*	0.2564	7.36
Medical Surv.	19.21	0.0001*	0.3680	7.52
A3s				
Lead Study	1.03	0.3137	0.0107	7.39
Medical Surv.	1.55	0.2196	0.0341	8.54

Regression Equations:
Medical Surveillance $Log_{10}FEP = 1.231122779 + 0.018619683COHb(mean)$
Lead Study $Log_{10}FEP = 1.266895939 + 0.016914350COHb(mean)$

*$\alpha = 0.05$

TABLE H-10B

Correlation Between Carboxyhemoglobin and Free Erythrocyte Protoporphyrin
Main Effects

Effect	F	p
Weapons System	29.70	0.0001*
Population	3.16	0.0766
COHb	36.59	0.0001*
Day	1.94	0.1647
Interaction (COHb*Weapons System)	13.25	0.0003*

*$\alpha = 0.05$

TABLE H-10C

Correlation Between Carboxyhemoglobin and Free Erythrocyte Protoporphyrin Effects by Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Population	0.57	0.4528	1.60	0.2083
COHb	41.68	0.0001*	4.26	0.0409*
Day	0.17	0.6805	4.52	0.0352*
Interaction (COHb*Population)	0.09	0.7691	0.48	0.4892

*$\alpha = 0.05$

TABLE H-10D

Correlation Between Carboxyhemoglobin and Free Erythrocyte Protoporphyrin Effects By Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
COHb	42.72	0.0001*	4.01	0.0472*
Day	0.19	0.6608	4.27	0.0407*

*$\alpha = 0.05$

TABLE H-10E

Correlation Between Carboxyhemoglobin and Free Erythrocyte Protoporphyrin Effects By Weapons System; By Population

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Lead Study Population				
COHb	26.56	0.0001*	1.03	0.3137
Medical Survey Population				
COHb	19.21	0.0001*	1.55	0.2196

*$\alpha = 0.05$

TABLE H-10F

Correlation Between Carboxyhemoglobin and Free Erythrocyte Protoporphyrin COHb (%) Means By Weapons System

	Weapons System					
	HIPs			A3s		
Day	Mean[1]	+/-SE[2]	n	Mean	+/-SE	n
1	4.90[3]	0.000	22	4.90	0.000	31
90	5.41	0.353	14	5.21	0.214	17
98	7.08	0.913	14	5.69	0.398	17
110	10.49	0.960	14	10.52	0.867	15
123	10.61	0.737	30	11.30	0.691	33
181	4.90	0.005	22	5.07	0.170	30

[1] arithmetic mean
[2] standard error of the mean
[3] values analytically measured as <5% COHb, reported as 4.90% for statistical analysis

TABLE H-10G

Correlation Between Carboxyhemoglobin and Free Erythrocyte Protoporphyrin COHb (%) Means By Weapons System; By Population

	HIPs					
	Lead Study Population			Medical Survey Population		
Day	Mean[1]	+/-SE[2]	n	Mean	+/-SE	n
1	4.90[3]	0.000	12	4.90	0.000	10
90	5.41	0.353	14	***	***	**
98	7.08	0.913	14	***	***	**
110	10.49	0.960	14	***	***	**
123	9.61	1.119	14	11.49	0.954	16
181	4.90	0.000	12	4.91	0.010	10
	A3s					
1	4.90	0.000	15	4.90	0.000	16
90	5.21	0.214	17	***	***	**
98	5.69	0.398	17	***	***	**
110	10.52	0.867	15	***	***	**
123	12.23	0.859	17	10.31	1.067	16
181	4.90	0.000	16	5.27	0.364	14

[1] arithmetic mean
[2] standard error of the mean
[3] values analytically measured as <5% COHb, reported as 4.90% for statistical analysis

TABLE H-10H

Correlation Between COHb and FEP with Day 181 (DPE) Removed
Fit to the Model

Model	F	p	R^2	CV
Overall	9.12	0.0001*	0.1856	7.48
By Weapons System				
HIPs	25.97	0.0001*	0.3659	6.79
A3s	0.50	0.6077	0.0090	7.66
By Weapons System, By Population				
<u>HIPs</u>				
Lead Study	17.09	0.0001*	0.3482	6.55
Medical Surv.	7.81	0.0026*	0.4046	7.76
<u>A3s</u>				
Lead Study	1.11	0.3358	0.0276	7.20
Medical Surv.	0.24	0.7878	0.0163	8.94

*$\alpha = 0.05$

TABLE H-10I

Correlation Between COHb and FEP with Day 181 Removed
Main Effects

Effect	F	p
Weapons System	21.83	0.0001*
Population	0.01	0.9382
COHb	6.60	0.0109*
Day	4.07	0.0451*
Interaction (COHb*Weapons System)	10.97	0.0001*

*$\alpha = 0.05$

TABLE H-10J

Correlation Between COHb and FEP with Day 181 Removed Effects By Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Population	0.23	0.6346	0.00	0.9925
COHb	5.14	0.0258*	0.75	0.3896
Day	16.04	0.0001*	0.19	0.6652
Interaction (COHb*Population)	0.31	0.5780	0.00	0.9571

*$\alpha = 0.05$

TABLE H-10K

Correlation Between COHb and FEP with Day 181 Removed Effects By Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
COHb	7.76	0.0065*	0.98	0.3237
Day	17.35	0.0001*	0.20	0.6522

*$\alpha = 0.05$

TABLE H-10L

Correlation Between COHb and FEP with Day 181 Removed Effects by Weapons System; By Population

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Lead Study Population				
COHb	7.12	0.0096*	1.91	0.1711
Day	12.28	0.0008*	1.44	0.2340
Medical Surv. Population				
COHb	0.77	0.3906	0.04	0.8513
Day	3.75	0.0651	0.38	0.5414

*$\alpha = 0.05$

TABLE H-11A

Correlation Between Carboxyhemoglobin and Hemoglobin
Fit to the Model

Effect	F	p	R^2	CV
Overall				
Complete	0.59	0.6682	0.0092	6.48
With Interaction	0.47	0.7955	0.0093	6.49
By Weapons System				
HIPs	3.03	0.0322*	0.0752	5.86
A3s	0.22	0.8792	0.0048	6.86
By Weapons System, By Population				
HIPs				
Lead Study	0.68	0.5801	0.0174	5.94
Medical Surv.	1.29	0.2880	0.0727	5.74
A3s				
Lead Study	0.13	0.8758	0.0028	6.79
Medical Surv.	0.10	0.9063	0.0046	1.17

*$\alpha = 0.05$

TABLE H-11B

Correlation Between Carboxyhemoglobin and Hemoglobin
Main Effects

Effect	F	p
Weapons System	0.81	0.3676
Population	1.29	0.2566
COHb	0.10	0.7470
Day	0.17	0.6842

$\alpha = 0.05$

TABLE H-11C

Correlation Between Carboxyhemoglobin and Hemoglobin Effects by Weapons System

	Weapons System			
	HIPs		A3s	
Effects	F	p	F	p
Population	6.80	0.0104*	0.26	0.6089
COHb	0.07	0.7967	0.15	0.6985
Day	2.39	0.1250	0.33	0.5654

*$\alpha = 0.05$

TABLE H-11D

Correlation Between Carboxyhemoglobin and Hemoglobin Effects By Weapons System; By Population

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Lead Study				
COHb	0.24	0.6232	0.19	0.6610
Day	1.25	0.2669	0.12	0.7327
Medical Surv.				
COHb	1.10	0.3012	0.00	0.9684
Day	1.00	0.3236	0.19	0.6616

$\alpha = 0.05$

TABLE H-11E

Correlation Between COHb and Hb with Day 181 (DPE) Removed
Fit to the Model

Model	F	p	R^2	CV
Overall	3.71	0.0061*	0.0685	6.09
By Weapons System				
HIPs	7.23	0.0002*	0.1941	5.50
A3s	1.62	0.1893	0.0426	6.39
By Weapons System, By Population				
<u>HIPs</u>				
Lead Study	5.36	0.0070*	0.1417	5.65
Medical Surv.	2.61	0.0950	0.1851	5.29
<u>A3s</u>				
Lead Study	0.04	0.9624	0.0010	5.95
Medical Surv.	3.77	0.0351*	0.2063	7.07

*$\alpha = 0.05$

TABLE H-11F

Correlation Between COHb and Hb with Day 181 (DPE) Removed
Main Effects

Effect	F	p
Weapons System	1.16	0.2826
Population	0.27	0.6017
COHb	5.43	0.0208*
Day	13.70	0.0003*

*$\alpha = 0.05$

TABLE H-11G

Correlation Between COHb and Hb with Day 181 Removed
Effects By Weapons System

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Population	2.14	0.1469	3.11	0.0809
COHb	4.34	0.0401*	1.31	0.2554
Day	15.81	0.0007*	2.94	0.0893

*α = 0.05

TABLE H-11H

Correlation Between COHb and Hb with Day 181 Removed
Effects by Weapons Systems; By Population

	Weapons System			
	HIPs		A3s	
Effect	F	p	F	p
Lead Study				
COHb	4.25	0.0432*	0.02	0.8867
Day	10.22	0.0021*	0.02	0.9003
Medical Surv.				
COHb	0.27	0.6097	5.19	0.0302*
Day	3.53	0.0732	7.14	0.0122*

*α = 0.05

TABLE H-12A

Correlation Between Nerve Conduction Velocity and Three Measures of Blood Lead: DPbB, Maximum (Peak) PbB and Rise In PbB From True Baseline: Main Effects

Time Period[1] / Nerve[2] / Effect	Statistic			
	F	p	R^2	CV
BL-->IPE				
MM	0.58	0.5685	0.0442	2199.73
DPbB	0.05	0.8254		
Weapons System	1.13	0.2975		
UM	3.75	0.0377**	0.2307	277.87
DPbB	5.93	0.0223**		
Weapons System	4.05	0.0549*		
MS	0.05	0.9486	0.0042	405.46
DPbB	0.00	0.9475		
Weapons System	0.08	0.7850		
US	0.11	0.9006	0.0087	232.18
DPbB	0.20	0.6561		
Weapons System	0.00	0.9443		
PM	1.43	0.2573	0.1029	-211.97
DPbB	1.93	0.1772		
Weapons System	1.93	0.1771		
SS	0.73	0.4911	0.0600	-386.57
DPbB	0.91	0.3488		
Weapons System	1.05	0.3167		
IPE-->DPE				
MM	0.10	0.9049	0.0087	-6774.11
DPbB	0.07	0.7966		
Weapons System	0.17	0.6808		
UM	1.28	0.2965	0.1003	-181.57
DPbB	2.50	0.1275		
Weapons System	0.02	0.8939		
MS	0.80	0.4616	0.0650	-349.48
DPbB	1.16	0.2918		
Weapons System	0.14	0.7078		
US	0.00	0.9986	0.0001	-274.50
DPbB	0.00	0.9668		
Weapons System	0.00	0.9874		
PM	0.30	0.7457	0.0263	-363.35
DPbB	0.27	0.6102		
Weapons System	0.19	0.6682		
SS	0.73	0.4946	0.0620	-163.71
DPbB	1.34	0.2594		
Weapons System	0.00	0.9709		

TABLE H-12A (Cont.)

Time Period[1] / Nerve[2] / Effect	F	p	R^2	CV
BL-->DPE				
MM	0.48	0.6233	0.0357	-873.84
DPbB	0.68	0.4172		
Weapons System	0.48	0.4935		
UM	0.35	0.7087	0.0261	-487.91
DPbB	0.00	0.9532		
Weapons System	0.64	0.4299		
MS	0.72	0.4970	0.0524	-934.79
DPbB	1.17	0.2902		
Weapons System	0.08	0.7813		
US	0.39	0.6830	0.0313	1531.92
DPbB	0.34	0.5625		
Weapons System	0.56	0.4628		
PM	0.56	0.5782	0.0429	-156.88
DPbB	1.01	0.3234		
Weapons System	0.27	0.6081		
SS	0.02	0.9774	0.0018	-137.59
DPbB	0.00	0.9934		
Weapons System	0.04	0.8339		
BL-->IPE				
MM	1.07	0.3586	0.0788	2159.56
MaxPbB	0.99	0.3292		
Weapons System	0.45	0.5088		
UM	0.99	0.3842	0.0737	306.00
MaxPbB	0.69	0.4318		
Weapons System	1.83	0.1880		
MS	0.42	0.6588	0.0328	399.59
MaxPbB	0.74	0.3965		
Weapons System	0.36	0.5563		
US	0.13	0.8745	0.0111	231.90
MaxPbB	0.26	0.6129		
Weapons System	0.01	0.9188		
PM	0.94	0.4052	0.0697	-215.86
MaxPbB	0.97	0.3348		
Weapons System	1.51	0.2305		
SS	1.64	0.2163	0.1246	-373.03
MaxPbB	2.68	0.1151		
Weapons System	1.45	0.2402		

TABLE H-12A (Cont.)

Time Period[1] Nerve[2] Effect	Statistic			
	F	p	R^2	CV
BL-->DPE				
MM	0.21	0.8148	0.0176	-1624.58
MaxPbB	0.32	0.5771		
Weapons System	0.01	0.9108		
UM	0.42	0.6651	0.0348	-506.12
MaxPbB	0.13	0.7225		
Weapons System	0.47	0.5014		
MS	2.50	0.1038	0.1788	-971.77
MaxPbB	4.67	0.0414**		
Weapons System	0.01	0.9046		
US	0.14	0.8735	0.0128	755.99
MaxPbB	0.14	0.7081		
Weapons System	0.23	0.6333		
PM	1.06	0.3628	0.0880	-142.44
MaxPbB	1.87	0.1854		
Weapons System	0.00	0.9759		
SS	0.84	0.4458	0.0708	-156.09
MaxPbB	1.61	0.2176		
Weapons System	0.36	0.5528		
BL-->IPE				
MM	0.82	0.4545	0.0758	-3928.96
RisePbB	0.44	0.5131		
Weapons System	0.66	0.4264		
UM	2.96	0.0751*	0.2281	458.98
RisePbB	2.76	0.1124		
Weapons System	4.95	0.0377**		
MS	0.54	0.5910	0.0512	936.12
RisePbB	0.42	0.5234		
Weapons System	0.96	0.3385		
US	0.21	0.8124	0.0216	354.57
RisePbB	0.40	0.5359		
Weapons System	0.01	0.9368		
PM	0.41	0.6682	0.0395	-199.86
Rise PbB	0.44	0.5169		
Weapons System	0.65	0.4298		
SS	1.81	0.1930	0.1671	-277.0
RisePbB	3.54	0.0761*		
Weapons System	0.57	0.4604		

TABLE H-12A (Cont.)

Time Period[1] Nerve[2] Effect	Statistic			
	F	p	R^2	CV
BL-->DPE				
MM	0.42	0.6585	0.0316	-875.69
RisePbB	0.57	0.4582		
Weapons System	0.11	0.7375		
UM	2.41	0.1096	0.1564	-454.11
RisePbB	4.02	0.0555*		
Weapons System	0.16	0.6939		
MS	0.15	0.8640	0.0112	-954.89
RisePbB	0.03	0.8546		
Weapons System	0.29	0.5945		
US	1.43	0.2589	0.1065	1471.24
RisePbB	2.39	0.1348		
Weapons System	0.10	0.7565		
PM	0.57	0.5751	0.0433	-156.85
RisePbB	1.03	0.3208		
Weapons System	0.30	0.5910		
SS	0.12	0.8838	0.0098	-137.04
RisePbB	0.20	0.6568		
Weapons System	0.10	0.7563		

[1] Time Period: BL = Baseline, IPE = Immediate Post-exercise, DPE = Delayed Post-exercise.
[2] Nerve: MM = Median motor, UM = Ulnar motor, MS = Median sensory, US = Ulnar sensory, PM = Peroneal motor, SS = Sural sensory

** $\alpha = 0.05$

* $\alpha = 0.10$

TABLE H-12B

Correlation Between Nerve Conduction Velocity and Three Measures of Blood Lead: DPbB, Maximum (Peak) PbB and Rise In PbB From True Baseline

Pooled Weapons System Populations

Blood Parameter Time Period[1] Nerve[2] Effect	Statistic			
	F	p	R^2	CV
DPbB				
BL-->IPE				
MM	0.02	0.8795	0.0009	2205.30
UM	3.08	0.0910*	0.1059	294.79
MS	0.03	0.8621	0.0012	398.19
US	0.21	0.6479	0.0085	227.52
PM	0.91	0.3498	0.0337	-215.73
SS	0.42	0.5239	0.0171	-386.95
IPE-->DPE				
MM	0.03	0.8680	0.0012	-6656.46
UM	2.66	0.1163	0.0996	-177.82
MS	1.51	0.2312	0.0592	-343.20
US	0.00	0.9599	0.0001	-268.19
PM	0.42	0.5229	0.0180	-356.88
SS	1.52	0.2303	0.0619	-160.12
BL-->DPE				
MM	0.49	0.4899	0.0178	-865.43
UM	0.06	0.8154	0.0021	-484.68
MS	1.41	0.2460	0.0495	-918.70
US	0.22	0.6418	0.0088	1518.29
PM	0.87	0.3582	0.0326	-154.66
SS	0.00	0.9759	0.0000	-135.04
MaxPbB				
BL-->IPE				
MM	1.73	0.2005	0.0622	2136.56
UM	0.15	0.7001	0.0058	310.86
MS	0.51	0.4834	0.0191	394.61
US	0.27	0.6801	0.0107	227.26
PM	0.36	0.5559	0.0135	-217.97
SS	1.79	0.1938	0.0693	-376.54

TABLE H-12B (Cont.)

Time Period[1] Nerve[2] Effect	Statistic			
	F	p	R^2	CV
BL-->DPE				
MM	0.42	0.5243	0.0171	-1590.82
UM	0.37	0.5477	0.0153	-500.47
MS	5.21	0.0317**	0.1783	-951.61
US	0.04	0.8448	0.0018	742.72
PM	2.22	0.1499	0.0880	-139.31
SS	1.35	0.2571	0.0555	-153.91
Rise in PbB				
BL-->IPE				
MM	1.00	0.3292	0.0454	-3896.95
UM	0.81	0.3795	0.0370	500.31
MS	0.12	0.7339	0.0056	935.26
US	0.44	0.5169	0.0213	345.66
PM	0.18	0.6788	0.0083	-198.19
SS	3.11	0.0938*	0.1407	-273.84
BL-->DPE				
MM	0.76	0.3913	0.0273	-861.22
UM	4.81	0.0370**	0.1513	-446.98
MS	0.00	0.9521	0.0001	-942.26
US	2.87	0.1029	0.1028	1444.46
PM	0.86	0.3628	0.0319	-154.71
SS	0.16	0.6968	0.0059	-134.64

[1] Time Period: BL = Baseline, IPE = Immediate Post-exercise, DPE = Delayed Post-exercise.
[2] Nerve: MM = Median motor, UM = Ulnar motor, MS = Median sensory, US = Ulnar sensory, PM = Peroneal motor, SS = Sural sensory
**$\alpha = 0.05$
*$\alpha = 0.10$

APPENDIX I

Data Tables for Skin Temperature and Nerve Conduction Velocity Measurement at Baseline, Immediate Post-exercise and Delayed Post-exercise

TABLE I-1

Baseline NCV values (m/sec) (no temperature adjustment)[a]

Subject	MM	UM	MS	US	PM	SS
2AB	58.4	59.9	63.6	59.8	52.3	44.2
3AB	57.9	60.8	64.9	58.9	50.3	43.8
4AB	59.1	41.3	60.2	--	48.6	39.8
5AB	60.4	60.1	59.5	60.9	48.4	41.7
6AB	62.5	62.5	65.0	64.6	50.3	44.9
7AB	66.6	70.4	63.8	73.1	56.1	47.3
8AB	58.0	54.0	58.6	54.6	52.0	42.7
9AB	60.6	61.0	58.6	59.5	49.2	44.2
10AB	62.5	61.5	61.9	60.6	50.3	40.7
12AB	63.9	65.7	66.9	64.6	52.5	43.8
13AB	58.0	62.5	62.5	63.5	48.5	42.7
14AB	59.2	63.4	62.5	65.3	48.0	44.9
15AB	65.5	50.8	61.1	58.8	51.3	39.8
16AB	61.3	61.6	62.5	65.5	54.6	41.7
17AB	61.4	61.6	63.1	63.0	46.3	38.4
18AB	58.0	57.4	62.5	60.2	52.1	38.0
19AB	57.0	56.8	56.9	59.1	48.0	35.0
20AB	59.9	63.5	62.5	69.0	54.9	--
21AB	58.0	56.5	62.5	58.8	56.2	38.9
22AB	55.8	60.9	61.4	65.2	55.5	40.2
23AB	60.0	62.5	57.8	62.5	52.9	43.8
24AB	58.8	57.1	59.9	61.5	56.3	44.4
26AB	65.1	63.5	64.5	65.5	52.2	43.3
27AB	66.3	68.2	65.1	64.7	54.8	43.1
28AB	57.5	60.0	62.5	67.2	51.0	39.2
29AB	56.6	62.5	61.2	60.6	50.3	45.0
30AB	62.5	64.6	63.9	66.9	58.8	47.8
31AB	60.0	64.5	61.8	63.0	53.0	37.2
Mean	60.4	60.5	62.0	62.8	52.0	42.1
SD	3.0	5.5	2.4	3.9	3.1	3.1
SE	0.6	1.0	0.4	0.7	0.6	0.6
n	28	28	28	27	28	27

[a]MM = median motor, UM = ulnar motor, MS = median sensory, US = ulnar sensory, PM = peroneal motor, SS = sural sensory.

TABLE I-2

Immediate Post-exposure NCV Values (m/sec) (no temperature adjustment)[a]

Subject	MM	UM	MS	US	PM	SS
2AB	61.4	60.8	66.1	62.5	54.1	41.7
3AB	60.1	63.4	61.9	61.6	56.5	40.7
4AB	61.4	40.3	59.0	--	47.9	38.9
5AB	60.5	60.9	60.4	63.4	48.5	39.8
6AB	62.5	61.5	63.8	62.5	52.0	41.7
7AB	63.8	69.2	63.8	65.8	54.6	46.0
8AB	59.2	57.6	60.2	57.6	51.6	41.7
9AB	59.6	63.3	61.5	62.5	48.3	42.7
10AB	62.5	63.5	62.5	60.6	53.8	40.7
12AB	61.2	62.5	65.2	62.5	53.7	41.7
13AB	61.3	63.4	60.2	64.4	45.7	40.7
14AB	61.4	64.3	63.7	67.2	49.4	43.8
15AB	65.3	50.0	62.5	58.6	50.6	41.7
16AB	55.8	63.5	62.5	65.5	51.4	38.9
17AB	60.2	59.8	61.3	67.2	44.3	--
18AB	56.1	56.7	60.2	60.7	50.1	38.9
19AB	60.2	62.5	61.3	63.4	46.9	39.8
20AB	57.8	64.6	61.2	64.5	53.1	--
21AB	59.1	56.5	62.5	61.6	51.5	38.9
22AB	55.2	62.5	56.4	63.4	55.0	39.8
23AB	57.8	59.7	58.9	62.5	52.0	43.8
24AB	59.0	56.2	57.8	58.8	50.6	41.7
26AB	61.3	63.5	62.5	65.6	51.4	41.7
27AB	63.8	68.2	63.8	67.1	53.4	39.8
28AB	59.5	60.8	64.7	65.2	49.1	41.7
29AB	56.7	66.0	59.0	58.8	46.1	39.8
30AB	66.9	63.6	62.5	64.6	56.9	44.9
31AB	61.2	67.8	60.8	62.5	49.7	39.8
Mean	60.4	61.2	61.6	63.0	51.0	41.2
SD	2.8	5.7	2.2	2.7	3.2	1.9
SE	0.5	1.1	0.4	0.5	0.6	0.4
n	28	28	28	27	28	26

[a]MM = median motor, UM = ulnar motor, MS = median sensory, US = ulnar sensory,PM = peroneal motor, SS = sural sensory.

TABLE I-3

Delayed Post-exposure NCV Values (m/sec) (no temperature adjustment)[a]

Subject	MM	UM	MS	US	PM	SS
2AB	60.3	59.1	63.7	60.9	54.0	41.7
3AB	60.3	61.6	62.5	62.5	53.4	39.8
4AB	60.3	40.6	62.5	--	46.4	38.9
5AB	60.4	63.3	62.5	65.9	49.1	36.4
6AB	62.5	60.7	61.3	65.4	50.0	42.7
7AB	60.0	64.5	60.0	61.5	51.1	41.7
8AB	59.2	55.4	60.3	54.7	51.4	40.7
9AB	60.6	61.0	60.5	63.3	47.9	41.2
10AB	65.1	65.6	62.5	60.5	47.5	40.7
11AB	53.7	54.7	59.3	57.4	46.4	38.9
12AB	61.2	61.5	62.5	61.5	54.6	39.8
13AB	62.5	62.5	62.5	64.4	48.0	40.7
14AB	58.3	61.6	60.3	65.0	49.0	40.7
15AB	65.4	50.3	59.8	--[b]	51.7	42.7
16AB	60.1	61.6	61.3	63.4	52.1	42.7
17AB	59.3	61.6	61.4	60.7	44.8	--
18AB	58.1	58.3	62.5	65.2	49.0	38.0
19AB	57.1	59.2	57.0	57.7	45.2	37.2
20AB	--	--	--	--	--	--
21AB	60.9	55.7	62.5	58.8	53.7	41.7
22AB	57.4	63.4	60.8	65.1	52.6	39.8
23AB	57.9	58.3	57.9	61.6	52.7	42.7
24AB	--	--	--	--	--	--
25AB	57.9	61.6	65.1	67.5	50.7	41.7
26AB[c]	58.8	59.8	61.3	64.4	50.4	40.7
27AB	61.2	63.5	62.5	61.5	53.1	38.9
28AB	59.5	60.8	67.0	68.0	50.9	40.7
29AB	56.7	61.6	60.1	62.5	52.5	41.7
30AB	--	--	--	--	--	--
31AB	62.5	64.5	60.0	62.5	49.7	37.2
Mean	59.9	59.7	61.5	62.5	50.3	40.4
SD	2.5	5.1	2.0	3.2	2.7	1.3
SE	0.5	1.0	0.4	0.6	0.5	0.4
n	27	27	27	25	27	26

[a]MM = median motor, UM = ulnar motor, MS = median sensory, US = ulnar sensory, PM = peroneal motor, SS = sural sensory.
[b]Median to ulnar crossover
[c]NCV measurement took place at Argonne National Laboratory, Argonne, IL, on 10/2/89.

TABLE I-4

Temperature-adjusted NCV Values (m/sec) for Immediate Post-exercise

Subject	MM	UM	MS	US	PM	SS
1AB	-	-	-	-	-	-
2AB	60.9	60.3	65.3	61.7	56.4	41.7
3AB	59.6	62.9	60.4	60.1	52.6	40.7
4AB	62.4	41.0	58.8	-	47.9	38.9
5AB	61.3	61.7	64.0	67.2	47.3	41.1
6AB	63.3	62.3	64.3	63.0	52.9	41.5
7AB	63.8	69.2	64.3	66.4	52.8	45.8
8AB	59.2	57.6	58.7	56.2	51.2	41.9
9AB	59.1	62.8	61.0	62.0	48.9	42.5
10AB	62.2	63.2	64.6	62.7	53.4	41.4
11AB	-	-	-	-	-	-
12AB	60.9	62.2	65.2	62.5	53.2	41.3
13AB	62.6	64.7	61.5	65.8	44.6	42.6
14AB	61.6	64.6	63.4	66.9	48.0	43.1
15AB	65.6	50.2	63.0	59.1	51.4	41.9
16AB	56.5	64.3	66.8	70.0	53.2	40.9
17AB	60.4	60.0	61.3	67.2	42.3	-
18AB	57.3	57.9	60.7	61.2	49.1	37.9
19AB	59.9	62.2	61.8	63.9	46.9	38.0
20AB	59.0	66.0	62.2	65.6	52.6	-
21AB	58.6	56.0	62.8	61.8	50.2	39.1
22AB	55.2	62.5	59.1	66.4	54.8	39.8
23AB	55.7	57.5	59.1	62.8	53.8	46.2
24AB	59.7	56.9	59.5	60.5	51.7	43.5
25AB	-	-	-	-	-	-
26AB	59.5	61.7	64.1	67.3	50.1	44.4
27AB	63.5	67.9	66.8	70.3	55.9	40.8
28AB	61.0	62.3	66.6	67.1	49.1	42.6
29AB	57.9	67.4	61.0	60.8	47.5	41.0
30AB	67.2	63.9	66.6	68.8	55.0	47.8
31AB	60.4	67.0	61.3	63.0	48.7	38.5
Mean	60.5	61.3	62.6	64.1	50.8	41.7
SD	2.8	5.7	2.6	3.5	3.4	2.4
SE	0.5	1.1	0.5	0.7	0.6	0.5
n	28	28	28	27	28	26

[a]IPE NCV values were temperature adjusted by the method of de Jesus (1973); IPE values were adjusted to BL limb temperatures.

TABLE I-5

Delayed Post-exercise (m/sec) (with temperature adjustment)[a]

Subject	MM	UM	MS	US	PM	SS
2AB	60.0	58.8	59.6	57.0	54.4	42.4
3AB	60.6	61.8	61.7	61.7	50.8	40.1
4AB	59.8	40.3	61.7	--	--	37.9
5AB	60.4	63.3	63.3	66.7	48.9	35.6
6AB	60.4	58.7	60.5	64.6	49.6	42.2
7AB	62.0	66.7	70.4	72.1	51.3	44.2
8AB	59.0	55.2	59.8	54.2	50.5	39.8
9AB	60.3	60.7	61.0	63.8	48.7	42.1
10AB	65.1	65.6	62.8	60.8	46.7	40.9
11AB	54.8	55.8	59.3	57.4	46.4	38.6
12AB	62.0	62.3	62.5	61.5	56.0	39.1
13AB	63.0	63.0	62.8	64.6	47.4	40.2
14AB	58.3	61.6	60.8	65.5	49.2	40.9
15AB	65.4	50.3	57.3	--	49.8	41.5
16AB	60.1	61.6	62.1	64.2	51.0	41.6
17AB	60.8	63.2	62.4	61.7	44.8	--
18AB	58.3	58.5	61.7	64.4	48.0	36.9
19AB	57.6	59.7	57.0	57.7	43.7	34.8
20AB	--	--	--	--	--	--
21AB	60.9	55.7	62.5	58.8	52.4	41.0
22AB	57.4	63.4	61.8	66.2	51.5	41.7
23AB	58.4	58.8	57.6	61.3	52.5	46.0
24AB	--	--	--	--	--	--
25AB	58.1	61.8	65.4	67.8	50.3	41.4
26AB	58.8	59.8	65.0	68.3	50.4	43.7
27AB	61.2	63.5	63.3	62.3	50.9	38.4
28AB	59.5	60.8	65.9	66.9	49.6	39.5
29AB	55.1	59.8	60.1	62.5	51.6	41.9
30AB	--	--	--	--	--	--
31AB	62.5	64.5	60.2	62.8	49.5	37.4
Mean	60.0	59.8	61.8	63.0	49.8	40.4
SD	2.5	5.2	2.0	4.0	2.7	2.6
SE	0.5	1.0	0.5	0.8	0.5	0.5
n	27	27	27	25	27	26

[a]MM = median motor, UM = ulnar motor, MS = median sensory, US = ulnar sensory, PM = peroneal motor, SS = sural sensory.

TABLE I-6

Individual Differences Between Baseline and Immediate Post-exposure NCV Values (m/sec) (no temperature adjustment)[a]

Subject	DMM	DUM	DMS	DUS	DPM	DSS
2AB	3.0	0.9	2.5	2.7	1.8	-2.5
3AB	2.2	2.6	-3.0	2.7	6.2	-3.1
4AB	2.3	-1.0	-1.2	--	-0.7	-0.9
5AB	0.1	0.8	0.9	2.5	0.0	-1.9
6AB	0.0	-1.0	-1.2	-2.1	1.7	-3.2
7AB	-2.8	-1.2	0.0	-7.3	-1.5	-1.3
8AB	1.2	3.6	1.6	3.0	-0.4	-1.0
9AB	-1.0	2.3	2.9	3.0	-0.9	-1.5
10AB	0.0	2.0	0.6	0.0	3.5	0.0
12AB	-2.7	-3.2	-1.7	-2.1	1.2	-2.1
13AB	3.3	0.9	-2.3	0.9	-2.8	-2.0
14AB	2.2	0.9	1.2	1.9	1.4	-1.1
15AB	-0.2	-0.8	1.4	-0.2	-0.7	1.9
16AB	-5.5	1.9	0.0	0.0	-3.2	-2.8
17AB	-1.2	-1.8	-1.8	4.2	-2.0	--
18AB	-1.9	-0.7	-2.3	0.5	-2.0	0.9
19AB	3.2	5.7	4.4	4.3	-1.1	4.8
20AB	-2.1	1.1	-1.3	-4.5	-1.8	--
21AB	1.1	0.0	0.0	2.8	-4.7	0.0
22AB	-0.6	1.6	-5.0	-1.8	0.0	-0.4
23AB	-2.2	-2.8	0.9	0.0	-0.9	0.0
24AB	0.2	-0.9	-2.1	-2.7	-5.7	-2.7
26AB	-3.8	0.0	-2.0	0.1	-0.8	-1.6
27AB	-2.5	0.0	-1.3	2.4	-1.4	-3.3
28AB	2.0	0.8	2.2	-2.0	-0.9	2.5
29AB	0.1	3.5	-2.2	-1.8	-4.2	-5.2
30AB	4.4	-1.0	-1.4	-2.3	-1.9	-2.9
31AB	1.2	3.3	-1.0	-0.5	-3.3	2.6

[a]A negative sign indicates a decrease in NCV from BL to IPE.

TABLE I-7

Individual Differences Between Baseline and Delayed Post-exposure NCV Values (m/sec) (no temperature adjustment)[a]

Subject	DMM	DUM	DMS	DUS	DPM	DSS
2AB	1.9	-0.8	0.1	1.1	1.7	-2.5
3AB	2.4	0.8	-2.4	3.6	3.1	-4.0
4AB	1.2	-0.7	2.3	--	-2.2	-0.9
5AB	0.0	3.2	3.0	5.0	0.7	-5.3
6AB	0.0	-1.8	-3.7	0.8	-0.3	-2.2
7AB	-6.6	-5.9	-3.8	-11.6	-5.0	-5.6
8AB	1.2	1.4	1.7	0.1	-0.6	-2.0
9AB	0.0	0.0	1.9	3.8	-1.3	-3.0
10AB	2.6	4.1	0.6	-0.1	-2.8	0.0
11AB	-3.6	-2.9	-1.0	-3.3	2.6	-2.8
12AB	-2.7	-4.2	-4.4	-3.1	2.1	-4.0
13AB	4.5	0.0	0.0	0.9	-0.5	-2.0
14AB	-0.9	-1.8	-2.2	-0.3	1.0	-4.2
15AB	-0.1	-0.5	-1.3	--	0.4	2.9
16AB	-1.2	0.0	-1.2	-2.1	-2.5	1.0
17AB	1.3	0.0	-1.7	-2.3	-1.5	--
18AB	0.1	0.9	0.0	2.3	-3.1	0.0
19AB	0.1	2.4	0.1	-1.4	-2.8	2.2
20AB	--	--	--	--	--	--
21AB	2.9	-0.8	0.0	0.0	-2.5	2.8
22AB	1.6	2.5	-0.6	-0.1	-2.9	-0.4
23AB	-2.1	-4.2	0.1	-0.9	-0.2	-1.1
24AB	--	--	--	--	--	--
25AB	-3.4	-1.9	-1.5	-2.1	-3.8	-4.3
26AB	-6.3	-3.7	-3.2	-1.1	-1.8	-2.6
27AB	-5.1	-4.7	-2.6	-3.2	-1.7	-4.2
28AB	2.0	0.8	4.5	0.8	-0.1	1.5
29AB	0.1	-0.9	-1.1	1.9	2.2	-3.3
30AB	--	--	--	--	--	--
31AB	2.5	0.0	-1.8	-0.5	-3.3	0.0
Mean	-0.3	-0.7	-0.7	-0.5	-1.0	-1.7
SD	2.8	2.5	2.1	3.2	2.1	2.4
SE	0.5	0.5	0.4	0.6	0.4	0.5
n	27	27	27	25	27	26

[a]A negative sign indicates a decrease in NCV from BL to IPE.

TABLE I-8

Individual Differences Between Baseline and Temperature-adjusted Immediate Post-exposure NCV Values (m/sec)[a]

Subject	DMM	DUM	DMS	DUS	DPM	DSS
HIP Subjects						
2AB	2.5	0.4	1.7	1.9	4.1	-2.5
5AB	0.9	1.6	4.5	6.3	-1.1	-0.6
6AB	0.8	-0.2	-0.7	-1.6	2.6	-3.4
14AB	2.4	1.2	0.9	1.6	0.0	-1.8
16AB	-4.8	2.7	4.3	4.5	-1.4	-0.8
17AB	-1.0	-1.6	-1.8	4.2	-4.0	--
18AB	-0.7	0.5	-1.8	1.0	-3.0	-0.1
20AB	-0.9	2.5	-0.3	-3.4	-2.3	--
22AB	-0.6	1.6	-2.3	1.2	-0.2	-0.4
24AB	0.9	-0.2	-0.4	-1.0	-4.6	-0.9
29AB	3.5	2.3	4.1	-0.1	-1.9	3.4
29AB	1.3	4.9	-0.2	0.2	-2.8	-4.0
30AB	4.7	-0.7	2.7	1.9	-3.8	0.0
31AB	0.4	2.5	-0.5	0.0	-4.3	1.3
M109A3 Subjects						
1AB	--	--	--	--	--	--
3AB	1.7	2.1	-4.5	1.2	2.3	-3.1
4AB	3.3	-0.3	-1.4	--	-0.7	-0.9
7AB	-2.8	-1.2	0.5	-6.7	-3.3	-1.5
8AB	1.2	3.6	0.1	1.6	-0.8	-0.8
9AB	-1.5	1.8	2.4	2.5	-0.3	-1.7
10AB	-0.3	1.7	2.7	2.1	3.1	0.7
11AB	--	--	--	--	--	--
12AB	-3.0	-3.5	-1.7	-2.1	0.7	-2.5
13AB	4.6	2.2	-1.0	2.3	-3.9	-0.1
15AB	0.1	-0.6	1.9	0.3	0.1	2.1
19AB	2.9	5.4	4.9	4.8	-1.1	3.0
21AB	0.6	-0.5	-0.3	3.0	-6.0	0.2
23AB	-4.3	-5.0	1.3	0.3	0.9	2.4
25AB	--	--	--	--	--	--
26AB	-5.6	-1.8	-0.4	1.8	-2.1	1.1
27AB	-2.8	-0.3	1.7	5.6	1.1	-2.3

[a]IPE NCV values were adjusted to BL skin temperatures by the method of de Jesus (1973). Negative values indicate a decrease in NCV from BL to IPE.

TABLE I-9

Individual Differences between Baseline and Delayed Post-exposure NCV values (m/sec) (with temperature adjustment)[a]

Subject	DMM	DUM	DMS	DUS	DPM	DSS
HIP Subjects						
2AB	-1.6	-1.1	-4.0	-2.8	2.1	-1.8
5AB	0.0	3.2	3.8	5.8	0.5	-6.1
6AB	-2.1	-3.8	-4.5	0.0	-0.7	-2.7
14AB	-0.9	-1.8	-1.7	0.2	1.2	-4.0
16AB	-1.2	0.0	-0.4	-1.3	-3.6	-0.1
17AB	-0.6	1.6	-0.7	-1.3	-1.5	--
18AB	0.3	1.1	-0.8	4.2	-4.1	-1.1
20AB	--	--	--	--	--	--
22AB	1.6	2.5	0.4	1.0	-4.0	1.5
24AB	1.6	-0.4	0.5	-1.3	-2.3	-0.8
28AB	2.0	0.8	3.4	-0.3	-1.4	0.3
29AB	-1.5	-2.7	-1.1	1.9	1.3	-3.1
30AB	--	--	--	--	--	--
31AB	2.5	0.0	-1.6	-0.2	-3.5	0.2
M109A3 Subjects						
1AB	1.3	1.9	1.0	1.7	-1.2	-3.8
3AB	2.7	1.0	-3.2	2.8	0.5	-3.7
4AB	0.7	-1.0	1.5	--	--	-1.9
7AB	-4.6	-3.7	6.6	-1.0	-4.8	-3.1
8AB	1.0	1.2	1.2	-0.4	-1.5	-2.9
9AB	-0.3	-0.3	2.4	4.3	-0.5	-2.1
10AB	2.6	4.1	0.9	0.2	-3.6	0.2
11AB	-2.5	-1.8	-1.0	-3.3	2.6	-3.1
12AB	-1.9	-3.4	-4.4	-3.1	3.5	-4.7
13AB	5.0	0.5	0.3	1.1	-1.1	-2.5
15AB	-0.1	-0.5	-3.8	--	-1.5	1.7
19AB	0.6	2.9	0.1	-1.4	-4.3	-0.2
21AB	2.9	-0.8	0.0	0.0	-3.8	2.1
23AB	-1.6	-3.7	-0.2	-1.2	-0.4	2.2
25AB	-3.2	-1.7	-1.2	-1.8	-4.2	-4.6
26AB	-6.3	-3.7	0.5	2.8	-1.8	0.4
27AB	-5.1	-4.7	-1.8	-2.4	-3.9	-4.7
Mean	-0.3	-0.6	-0.3	0.2	-1.5	-1.7
SD	2.6	2.4	2.6	2.4	2.4	2.3
SE	0.5	0.5	0.5	0.5	0.5	0.4
n	27	27	27	25	27	25

[a]A negative sign indicates a decrease in NCV from BL to IPE.

TABLE I-10

Individual Changes in Nerve Conduction Velocity (m/sec) from Immediate Post-exercise to Delayed Postexercise[a]

Subject	DMM	DUM	DMS	DUS	DPM	DSS
HIP Subjects						
2AB	-0.9	-1.5	-5.7	-4.7	-2.0	0.7
5AB	-0.9	1.6	-0.7	-0.5	1.6	-5.5
6AB	-2.9	-3.6	-3.8	1.6	-6.3	0.7
14AB	-3.3	-3.0	-2.6	-1.4	1.2	-2.2
16AB	3.6	-2.7	-4.7	-5.8	-2.2	0.7
17AB	0.4	3.2	1.1	-5.5	2.5	--
18AB	1.0	0.6	1.0	3.2	-1.1	-1.0
20AB	--	--	--	--	--	--
22AB	2.2	0.9	2.7	-0.2	-3.3	1.9
24AB	0.7	-0.2	0.9	-0.3	2.3	0.1
28AB	-1.5	-1.5	-0.7	-0.2	0.5	-3.1
29AB	-2.8	-7.6	-0.9	1.7	4.1	0.9
30AB	--	--	--	--	--	--
31AB	2.1	-2.5	-1.1	-0.2	0.8	-1.1
M109A3 Subjects						
1AB	--	--	--	--	--	--
3AB	1.0	-1.1	1.3	1.6	-1.8	-0.6
4AB	-2.6	-0.7	2.9	--	--	-1.0
7AB	-1.8	-2.5	6.1	5.7	-1.5	-1.6
8AB	-0.2	-2.4	1.1	-2.0	-0.7	-2.1
9AB	1.2	-2.1	0.0	1.8	-0.2	-0.4
10AB	2.9	2.4	-1.8	-1.9	-6.7	-0.5
11AB	--	--	--	--	--	--
12AB	1.1	0.1	-2.7	-1.0	2.8	-2.2
13AB	0.4	-1.7	1.3	-1.2	2.8	-2.4
15AB	-0.2	0.1	-5.7	--	-1.6	-0.4
19AB	-2.3	-2.5	-4.8	-6.2	-3.2	-3.2
21AB	2.3	-0.3	-0.3	-3.0	2.2	1.9
23AB	2.7	1.3	-1.5	-1.5	-1.3	-0.2
25AB	--	--	--	--	--	--
26AB	-0.7	-1.9	0.9	1.0	0.3	-0.7
27AB	-2.3	-4.4	-3.5	-8.0	-5.0	-2.4

[a]MM = median motor; UM = ulnar motor; MS = median sensory; US = ulnar sensory; PM = peroneal motor; SS = sural sensory. Prior to calculating changes, NCV values were adjusted for differences in skin temperature according to the method of de Jesus et al (1973).

TABLE I-11

Baseline, Immediate Post-exposure, and Delayed Post-exposure Skin Temperatures (°C)[a]

Subject	SH_1[a]	SH_2[b]	SH_3[c]	EH_1	EH_2	EH_3	SL_1	SL_2	SL_3	EL_1	EL_2	EL_3
1AB	33.0	--	33.0	33.0	--	32.9	32.1	--	32.4	32.3	--	32.1
2AB	33.1	33.3	33.2	31.2	31.5	32.8	32.8	31.8	32.6	32.1	32.1	31.7
3AB	33.0	33.2	32.9	33.0	33.6	33.3	31.5	33.2	32.7	33.2	33.2	33.0
4AB	33.7	33.3	33.9	33.0	33.1	33.3	--	34.0	34.0	33.8	--	34.4
5AB	33.0	32.7	33.0	32.9	31.5	32.6	31.2	31.8	31.3	31.8	31.0	32.3
6AB	33.0	32.7	33.8	32.8	32.6	33.1	32.0	31.6	32.2	31.9	32.0	32.2
7AB	34.8	34.8	34.0	34.1	33.9	30.3	32.8	33.6	32.7	33.5	33.6	32.1
8AB	33.2	33.2	33.3	32.1	32.7	32.2	32.6	32.8	33.0	33.0	32.9	33.5
9AB	33.2	33.4	33.3	32.6	32.8	32.4	34.2	33.9	33.8	34.1	34.2	33.6
10AB	33.4	33.5	33.4	33.1	32.3	33.0	31.9	32.1	32.3	32.2	31.8	32.1
11AB	33.1	--	32.6	32.2	--	32.2	32.6	--	32.6	31.3	--	31.5
12AB	33.4	33.5	33.1	33.3	33.3	33.3	31.0	31.2	30.4	30.9	31.1	31.3
13AB	33.6	33.1	33.4	33.7	33.2	33.6	32.4	33.0	32.7	33.0	31.9	33.3
14AB	33.3	33.2	33.3	33.2	33.3	33.0	31.7	32.4	31.6	32.6	33.0	32.5
15AB	33.7	33.6	33.7	32.9	32.7	33.9	31.8	31.4	32.7	32.2	32.1	32.9
16AB	33.6	33.3	33.6	33.0	31.4	32.7	31.8	31.0	32.3	31.7	30.5	32.3
17AB	33.8	33.7	33.2	34.3	34.3	33.9	32.7	33.8	32.7	34.7	34.5	33.1
18AB	34.4	33.9	34.3	33.3	33.1	33.6	31.0	31.5	31.5	31.2	31.8	31.9
19AB	33.4	33.5	33.2	31.9	31.7	31.9	31.0	31.0	31.8	30.5	31.6	32.1
20AB	34.6	34.1	--	33.0	32.6	--	32.9	33.1	--	33.1	33.1	--
21AB	33.2	33.4	33.2	33.0	32.9	33.0	31.0	31.6	31.6	32.1	32.0	32.5
22AB	33.0	33.0	33.0	33.4	32.3	33.0	32.2	32.3	32.7	32.7	32.7	32.7
23AB	33.4	34.3	33.2	33.2	33.1	33.3	31.8	31.0	31.9	34.3	33.0	32.5
24AB	33.9	33.6	34.0	33.0	32.3	33.1	33.3	32.8	33.4	34.2	33.2	33.5
25AB	33.6	--	33.5	33.0	--	32.9	32.0	--	32.2	32.7	--	32.9
26AB	33.1	33.8	33.1	33.8	33.2	32.4	33.4	34.0	33.4	34.5	33.0	32.8
27AB	34.2	34.3	34.2	34.0	32.9	33.7	31.9	30.8	32.9	32.6	32.0	32.9
28AB	34.9	34.3	34.9	33.0	32.3	33.4	31.8	31.8	32.4	32.4	31.9	33.1
29AB	33.3	32.8	34.0	33.6	32.8	33.6	33.5	32.8	33.9	33.8	33.1	33.7
30AB	33.4	33.3	--	33.6	32.1	--	32.8	33.6	--	33.5	32.0	--
31AB	33.1	33.4	33.1	33.2	33.0	33.1	31.2	31.7	31.3	31.2	32.0	31.1

[a]SH_1 = Start, Baseline Hand Skin; EH_1 = End, Baseline Hand Skin; SL_1 = Start, Baseline Leg Skin; EL_1 = End, Baseline Leg Skin.
[b]SH_2 = Start, IPE Hand Skin; EH_2 End, IPE Hand Skin; SL_2 Start, IPE Leg Skin; EL_2 = End, IPE Leg Skin.
[c]SH_3 = Start, DPE Hand Skin; EH_3 = End, DPE Hand Skin; SL_3 = Start, DPE Leg Skin; EL_3 = End, DPE Leg Skin.
(Start = start of individual's NCV measurement period; end = end of individual's NCV measurement period.)

TABLE I-12

Limb Temperature Difference Baseline to Immediate Post-exercise, (°C)[a]

Subject	SH_1-SH_2	EH_1-EH_2	SL_1-SL_2	EL_1-EL_2
1AB	-	-	-	-
2AB	0.2	0.3	-1.0	0.0
3AB	0.2	0.6	1.7	0.0
4AB	-0.4	0.1	-	-
5AB	-0.3	-1.4	0.6	-0.8
6AB	-0.3	-0.2	-0.4	0.1
7AB	0.0	-0.2	0.8	0.1
8AB	0.0	0.6	0.2	-0.1
9AB	0.2	0.2	-0.3	0.1
10AB	0.1	-0.8	0.2	0.4
11AB	-	-	-	-
12AB	0.1	0.0	0.2	0.2
13AB	-0.5	-0.5	0.6	-1.1
14AB	-0.1	0.1	0.7	0.4
15AB	-0.1	-0.2	-0.4	-0.1
16AB	-0.3	-1.6	-0.8	-1.2
17AB	-0.1	0.0	1.1	-0.2
18AB	-0.5	-0.2	0.5	0.6
19AB	0.1	-0.2	0.0	1.1
10AB	-0.5	-0.4	0.2	0.0
21AB	0.2	-0.1	0.6	-0.1
22AB	0.0	-1.1	0.1	0.0
23AB	0.9	-0.1	-0.8	-1.3
24AB	-0.3	-0.7	-0.5	-1.0
25AB	-	-	-	-
26AB	0.7	-0.6	0.6	-1.5
27AB	0.1	-1.1	-1.1	-0.6
28AB	-0.6	-0.7	0.0	-0.5
29AB	-0.5	-0.8	-0.7	-0.7
30AB	-0.1	-1.5	0.8	-1.5
31AB	0.3	-0.2	0.5	0.8

[a]A negative sign indicates a decrease in temperature from BL to IPE.

APPENDIX J

Respiratory Protection During Firing Periods and Estimated Exposure

Information contained in the first table was developed during a visual review of videotapes provided by the Operational Test and Evaluation Agency. The video tapes documented live firing exercises of HIP howitzers at Ft. Sill, OK, during the periods 25 June through 23 July 1989.

TABLE J-1

Periods of Wearing Respiratory Protection during Mission Oriented Protective Posture (MOPP) Training

Date	Required Wear Time	Actual Wear Time	Number of High Zone Charges Fired HIPs	M109A3
6 July	1020-1041	Full	7	7
"	1041-1113	Full	7	-
"	1113-1134	None	9	-
"	1134-1152	None	7	-
7 July	0837-0856	Full	-	6
"	0856-0914	Full	7	-
"	0914-0930	Full	7	-
"	2132-2234	Full	-	-
"	2234-2243	Full	-	-
"	2243-2311	Full	-	-
8 July	0224-0242	None	-	-
"	0242-0301	None	-	-
"	0301-0327	0307-0327	-	-
"	0327-0340	Full	-	-
9 July	0234-0258	None	2	-
"	0258-0326	None	-	2
"	0326-0343	None	-	4
"	0343-0358	None	6	-
"	0358-0413	None	6	-
"	0738-0828	Full	5	-
"	0828-0853	Full	7	-
"	0853-0909	0853-0857	-	3
"	0909-0939	None	-	-

TABLE J-2

Field Exercise II. Air Concentration Correction for Masking

Subject	Total Rounds	Round Deficit	% Rounds[1]	Mean 8-Hr TWA[2]	Corrected 8-Hr TWA
<u>HIPs</u>					
2AB	317	28	8.8	14.56	13.28
5AB	194	26	13.4	11.80	10.22
14AB	261	14	5.4	11.00	10.40
17AB	194	26	13.4	11.45	9.92
20AB	317	28	8.8	17.60	16.05
22AB	194	26	13.4	13.27	11.49
28AB	194	26	13.4	33.01	28.59
29AB	317	28	8.8	10.17	9.28
30AB	194	26	13.4	19.82	17.16
<u>M109A3s</u>					
1AB	149	16	10.7	32.76	29.25
3AB	298	16	5.4	35.86	33.92
7AB	298	16	5.4	55.65	52.64
8AB	298	16	5.4	37.43	35.41
10AB	149	16	10.7	21.16	18.90
12AB	103	7	6.8	48.36	45.07
19AB	149	16	10.7	32.49	29.01
21AB	149	16	10.7	28.39	25.35
25AB	149	16	10.7	22.05	19.69

1. Round deficit/total rounds X 100 = % rounds
2. TWA = time weighted average (mg/m^3)

APPENDIX K

Relationship Between the Number of Rounds Fired and Resultant Concentration-time Product: Number of Rounds Fired to Equal the OSHA Permissible Exposure Limit

TABLE K-1

Concentration-time Product Estimates and Number of M119 Charges to Equal the PEL for Samples of Less than 10 Rounds: Various Studies

# rounds[1] / sample	# samples	Mean Ct[2] Product / round	±Mean SE Ct Product/round	#rounds[3] = PEL	Ref.
1	7	4942.55	69.81	5	This Study[4]
1	6	1459.00	312.79	17	Ref 2[5]
6	12	2788.43	730.49	11	This Study[5]
8	4	182.16	173.83	132	Ref 10[4]
8	3	1122.92	79.94	22	Ref 10[5]
8	10	2794.29	2580.06	9	This Study[5]
9	18	2489.00	1364.49	10	This Study[4]
10	9	1491.75	489.32	17	This Study[4]

[1] All rounds fired were charge M119
[2] The Concentration-time Product = $mg\text{-}min/m^3$
[3] PEL - Permissible Exposure Limit = 24,000 $mg\text{-}min/m^3$
[4] Samples taken in the cab of a HIP howitzer equipped with a cab filter
[5] Samples taken in the cab of a HIP howitzer or a M109A3 without a cab filter

TABLE K-2

Concentration-time Product Estimates with Varying Number of Rounds Fired in a Sample[1]

# rounds / sample	# samples	Mean Ct Product[2] / round	± SE Mean Ct product/round	# rounds to = PEL[3]
21	6	1124.82	255.80	22
24	14	452.79	252.00	53
32	4	153.26	3.40	157
53	3	496.63	456.19	49
71	5	296.07	127.12	81
94	10	596.28	267.31	41
175	5	205.68	120.06	117

[1] All samples were taken from HIP weapons in this study; each weapon with a cab filter
[2] The Concentration-time Product = $mg\text{-}min/m^3$
[3] PEL - Permissible Exposure Limit = 24,000 $mg\text{-}min/m^3$

TABLE K-3

Concentration-time Estimates for M203 Charges

# rounds[1] sample	# samples	Mean Ct[2] Product round	$\pm$SE Ct Product per round	#rounds[3] = PEL	Ref.
1	8	9456.5	1757.5	3	This Study[4]
8	4	167.66	83.16	143	Ref YPG[4]
8	4	3252.19	834.59	8	Ref YPG[5]
11-12	11	1048.21	178.54	23	Ref 2[5]
56	4	352.41	189.99	69	This Study[4]

[1] All rounds fired were charge M203
[2] The Concentration-time Product = mg-min/m^3
[3] PEL - Permissible Exposure Limit = 24,000 mg-min/m^3
[4] Samples taken in the cab of a HIP howitzer equipped with a cab filter
[5] Samples taken in the cab of a HIP howitzer without a cab filter